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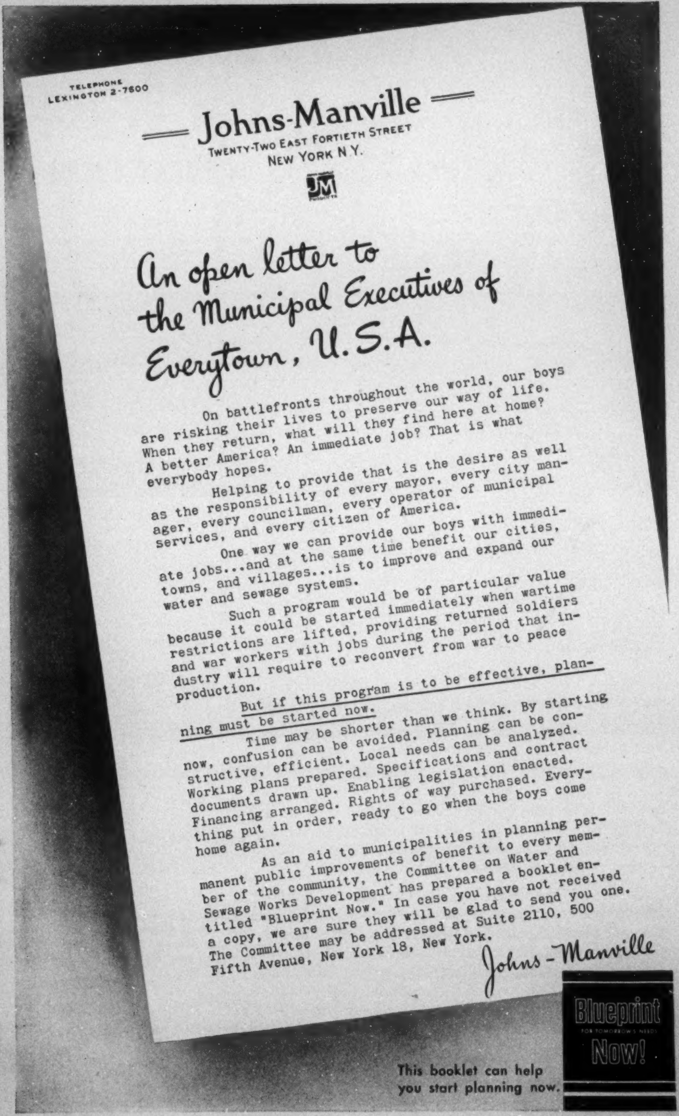

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An open letter to the Municipal Executives of Everytown, U.S.A.

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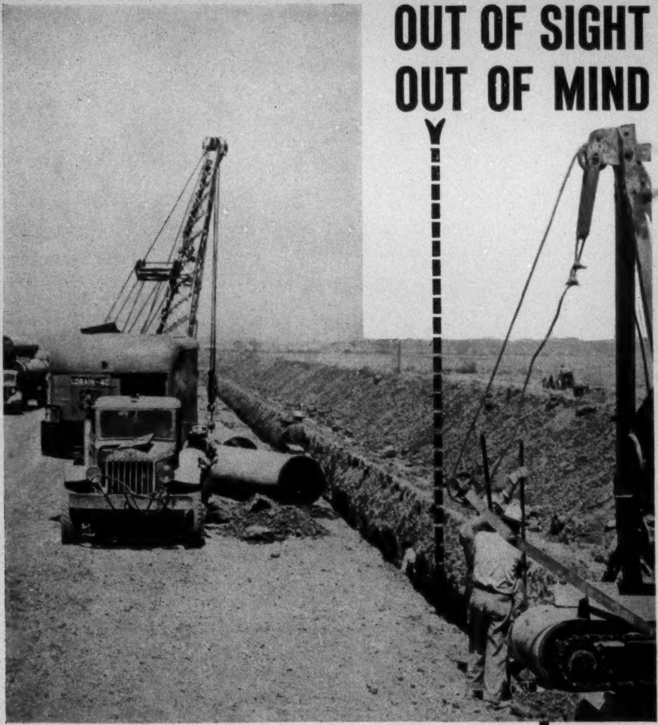

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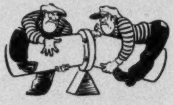

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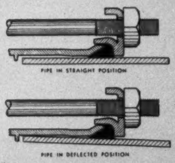

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CHLORINE-AMMONIA TREATMENT OF THE WATER SUPPLY OF AMHERST, MASSACHUSETTS†

BY JAMES E. FULLER*

[*Read February 17, 1944.*]

The Department of Bacteriology at the Massachusetts State College and Experiment Station has maintained, for some years, a service for the bacteriological testing of privately-owned water supplies, particularly those of farms and rural homes. In general, no public supplies are tested, the one exception being the water supply of the Town of Amherst which is tested regularly as a contribution to the community in which the College and Experiment Station are located. A considerable rural area in the outlying parts of the town is served by this supply. This area includes farms and dairy plants, and this fact is an added reason for the Experiment Station being interested in the testing and in the study of the town water supply.

In September, 1942, the Water Department of the town substituted chlorine-ammonia treatment of the water for chlorination which had been employed for about eighteen years. The installation of the new treatment afforded an opportunity for the study of possible changes that might occur in the bacterial flora of the water in the town's distribution system as the chloramine residual was being established and for some time subsequently.

All of the work represented in this report was carried out in close coöperation with officials of the Amherst Water Department whose contributions will be acknowledged at the end of this paper.

Amherst Water System. The Amherst Water Company, former owner of the town water supply, was incorporated in 1880, and water was distributed to the town the same year, probably through purchase or consolidation of the systems already existent. At first, the supply

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*Research Professor, Massachusetts Agricultural Experimental Station, Amherst, Mass.
†Contribution 512 of the Massachusetts Agricultural Experiment Station.

was taken from one reservoir fed by a brook. As the town grew and water needs increased, the General Court of the State granted permission, by means of legislative acts, for the Company to acquire more land, take water from other streams, and construct other reservoirs. According to the annual town report of December 31, 1941, the main system now consists of two storage reservoirs and an intake reservoir fed by several brooks on one water shed. There is a reserve supply on another shed, consisting of one storage reservoir fed by brooks. About 1,100 acres of land are owned by the town on the two sheds, which means that much of the land that constitutes these sheds is privately owned and is only imperfectly controlled by the town.

In February, 1941, the citizens of the town voted to purchase the water system from the Amherst Water Company, and the town took charge on November 1 of that year. The superintendent and foreman were retained in their positions by the town water commissioners, to the entire satisfaction of the community. Thus, we see that the Amherst system is quite an old one and that until about six years ago it was operated without the supervision of a trained engineer.

Chlorine treatment was installed in 1923; and in September, 1942, the chlorine-ammonia treatment was begun. Wallace and Tiernan equipment is employed. There is no sedimentation or filtration, and the intake reservoir is too small to permit it to function as a settling basin to any considerable extent, particularly in seasons of heavy use. The capacity of the reservoir is 2 mg.; and according to the annual report of December 1942, the average daily consumption of water for the year was 629,286 gal. The water is satisfactorily soft, but at certain times of the year it has a considerable content of organic matter and rather high color in consequence.

Experimental Studies

The Water Department used several collecting stations for the samples taken for this study. The first of these is owned by a family by the name of Alderman and is designated as the Alderman house in this report. It is only a few hundred feet from the chlorinating plant. The second station is the Town Hall, in the center, about three miles west of the chlorinating plant. The third is the North

Amherst school, two and one-half miles north of the center and five and one-half miles from the chlorinator. A few samples were taken at the Cushman School a mile or more east of North Amherst, but these results were grouped with those from North Amherst. Samples from these stations were taken and their chlorine residuals determined by representatives of the town Water Department. The author and his assistants also took samples and determined chlorine residuals from two college stations, Marshall Hall in which the Bacteriology Department is housed, and the college Infirmary nearby.

The chlorine-ammonia treatment had been in use for several weeks when this study was begun. Residuals were already established as far as the Town Hall, but not at North Amherst. As the accompanying tables show, residuals were slow in appearing at the college stations. The distributing system on the campus is privately owned by the College and is not subject to supervision by the town water officials. In recent years it has not been flushed as frequently as the town mains are, and there probably is a greater accumulation of organic matter in the mains.

Sterile glass-stoppered bottles were employed for collecting samples. These bottles contained sodium thiosulfate to stop the action of residual chlorine after the samples were taken. Samples were collected from taps at the several stations and brought into the laboratory within an hour or an hour and a half after they were collected. Residuals were determined at the taps when samples were taken.

The objectives of the study were: (1) To determine the numbers of bacteria by means of plate counts; (2) to isolate and identify to genus the bacteria appearing on the plates; (3) to make routine tests for the coliform group of bacteria.

Plate Counts. Nutrient agar was used for making the plate counts. The medium was prepared and plates were made according to Standard Methods of Water Analysis.* Two incubating temperatures were employed, 37° C and room temperature of about 22° C. Facilities were not available for maintaining 20° C as directed by Standard Methods. The standard procedure was followed in other

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*8th ed., 1936.

TABLE 1.—BACTERIA COUNTS AND CHLORINE RESIDUALS FROM TAP WATER WHILE CHLORAMINE RESIDUAL WAS BECOMING ESTABLISHED

	Town Stations									College Stations					
	Alderman House			Town Hall			N. Amherst School			Marshall Hall			Infirmary		
	Res.	22° C	37° C	Res	22° C	37° C	Res.	22° C	37° C	Res.	22° C	37° C	Res.	22° C	37° C
1942															
Oct. 21	0.15	30	19	0.05	38	14	tr.	28	17	—	48	25	—	40	18
Nov. 4	0.15	36	20	0.05	42	16	tr.	45	26	—	52	28	—	39	18
Nov. 18	0.15	36	18	0.08	41	17	0.02	40	25	tr.	32	15	tr.	23	5
Dec. 2	0.08	42	24	0.05	44	17	0.05	43	28	0.07	45	25	0.02	48	20
Dec. 10	0.16	21	14	0.08	24	8	0.08	30	21	0.04	34	15	tr.	33	16
Dec. 16	0.05	23	16	0.05	22	7	0.05	32	18	tr.	24	9	tr.	28	11
Dec. 28	0.08	25	18	0.05	23	11	0.05	30	20	0.04	21	11	0.03	24	12
1943															
Jan. 8	0.08	24	15	0.05	20	6	0.03	27	17	0.05	22	10	tr.	19	8
Average	—	30	18	—	32	12	—	34	21	—	35	17	—	32	13

respects. Accepted bacteriological technique was employed for isolating, purifying, and studying cultures. Cultures were identified according to Bergey's Manual of Determinative Bacteriology.†

Table 1 shows counts from samples collected from the several stations. It will be observed that the counts at room temperature exceeded considerably those at 37° C. This is usual, and in raw water the difference is much greater. The room-temperature counts from the stations were similar. The 37° C counts from the Town Hall were somewhat smaller than those from the other two stations. Those from the North Amherst school were only slightly greater than those from the Alderman house.

The particularly interesting thing about the table is that there was a sharp break downward in the room-temperature counts between December 2 and December 10. At this point, chromogenic bacteria ceased to appear on plates. The reason is not apparent. The 37° C counts also decreased somewhat at the same point. Counts from samples taken from the two State-College stations followed, in general, the trends shown by those from the town samples; the counts were of about the same magnitude and the same break downward occurred between December 2 and 10.

Counts from the raw water of the intake reservoir remained practically uniform for the same period. The room-temperature counts averaged between 200 to 250 per ml, and the counts at 37° C averaged from 35 to 50 per ml. Thus, it appears that the greatest reduction in counts from tap water as compared with raw water was in the bacteria that grow at room-temperature. One reason for this is the fact that most of the bacteria on the 37° C plates were resistant spore-forming, aerobic bacteria, and on the room-temperature plates these were in the minority. This was proved by isolation and partial identification of bacteria appearing on the plates.

The isolated bacteria were classified as to genus, as follows:

Bacillus group—aerobic spore-formers, from both room-temperature and 37° C plates.

Alcaligenes group—(no pigment), on room-temperature plates.

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†Williams and Wilkins Co., Baltimore, 5th ed., 1939.

Flavobacterium group—yellow pigment, common on room-temperature plates.

Bacterium group—only a few, on room-temperature plates. No pigment.

Staphylococci—few, brownish pigment, on 37° C plates.

Micrococci—tan, yellow, or brown pigment in some cultures but not in all. Limited to room-temperature plates.

About the time this study was started a problem was presented to the laboratory by a neighboring community. Some time after their introduction of chlorine-ammonia treatment as a substitute for chlorination, large numbers of red colonies of the *B. prodigiosus* group (*Serratia,* Bergey) began to appear on the plates. Examination of samples of filter sand showed it to be heavily seeded with these organisms. No red colonies, however, appeared in any of the plates made from the Amherst water. There was some increase of aerobic spore-forming bacteria, but no particular significance is indicated.

The plate counts showed no marked effect from the introduction of the chlorine-ammonia treatment in the Amherst water supply. The 37° C counts compared favorably with routine counts made when chlorine treatment was employed. Both 37° C and room-temperature counts made at intervals during the year following the period represented in Table 1 showed that the counts have continued to be of the same magnitude generally as those in the table.

Up to this point this report is of scientific rather than sanitary significance, and it is so presented. The more important results appeared in the coliform tests which are the subject of the remainder of this paper.

Presumptive Tests. The technique of Standard Methods of Water Analysis was employed in making the presumptive tests for coliform bacteria and in confirming positive tests. Lactose broth fermentation tubes (Durham type) were employed for making the presumptive tests. Five 10-ml and five 1-ml quantities of water were inoculated from each sample. Tubes were incubated and examined in 24 hrs., and all negative tubes were incubated an additional 24 hrs. Streakings were made on Endo's agar from all positive gas tubes, followed by tests for refermentation in lactose broth. Gram stains were made from Endo plates. Difco dehydrated media were used, and 37° C incubation was employed throughout.

Results of the tests are shown in Tables 2 and 3. Only two stations are represented in the tables, because it is from these stations that samples are taken for routine tests, and consequently records are available from these stations for several years. In the tables the dates are grouped into four periods:

TABLE 2.—FERMENTATION TESTS. DAYS ON WHICH TESTS WERE POSITIVE IN STATED AMOUNTS OF WATER

Period	Dates	Days tested	Days + 10 ml.	Days + 1 ml.	24 hrs. +	Confirmed Endo
Chlorine						
I	Sept., 1941 to Aug., 1942.					
	Town Hall	23	3	3	1 tube	1 tube
	N. Amherst	23	6	4	0	0
Chlorine-ammonia						
II	Sept., 1942 to Jan. 6, 1943.					
	Town Hall	12	4	2	0	0
	N. Amherst	12	3	0	0	0
III	Jan. 13, 1943 to Aug., 1943.					
	Town Hall	23	2	0	0	0
	N. Amherst	23	3	0	0	0
IV	Sept., 1943 to Jan., 1944.					
	Town Hall	14	10	7	0	0
	N. Amherst	11	8	4	0	0

Period I. A full year of chlorination before chlorine-ammonia treatment was begun.

Period II. The transition period during which the chloramine residual was being established through the distributing system.

Period III. The interim between Period II and the incidence of increased numbers of positive presumptive tests.

TABLE 3.—FERMENTATION TESTS. NUMBER AND PER CENT OF POSITIVE TESTS IN STATED AMOUNTS OF WATER

Period	Dates	10 ml.	10 ml.		10 ml.	1 ml.		
		total	+	%	Confirm.	+	%	Confirm.
Chlorine								
I	Sept., 1941 to Aug., 1942.							
	Town Hall	115	8	7	1	5	4.3	0
	N. Amherst	115	12	10	0	6	5.2	0
Chlorine-ammonia								
II	Sept., 1942 to Jan. 6, 1943.							
	Town Hall	60	12	20	0	2	3.3	0
	N. Amherst	60	6	10	0	0	0	0
III	Jan. 13, 1943 to Aug., 1943							
	Town Hall	115	5	4.3	0	0	0	0
	N. Amherst	105	7	6.6	0	0	0	0
IV	Sept., 1943 to Jan., 1944.							
	Town Hall	70	32	46	0	12	17.0	0
	N. Amherst	55	23	42	0	7	12.7	0

Period IV. The balance of the time through January, 1944.

Throughout Period I, samples were collected about once in two weeks. Since that time, collections have been made three or four times each month. All samples were collected by representatives of the Amherst Water Department.

Table 2 shows the number of days during each period that samples were taken, and the number on which positive presumptive tests resulted. It will be observed that the incidence of positive tests was about the same in Periods I and III, and during the transition period (II) it was a little higher. Periods II and III represent one year of chlorine-ammonia treatment. The incidence of positive tests suddenly began to increase in August of Period III, and during Period IV most of the samples from both stations gave positive tests. This high incidence is still continuing, as this paper is being written in

February, 1944. The number of positive 10-ml tubes was substantially larger than the number of positive 1-ml tubes throughout all four periods.

Table 3 is a restatement on a percentage basis of the data of Table 2. The numbers of positive tests are calculated as percentages of the numbers of tubes inoculated. In this table the substantial increase in the incidence of positive tests in Period IV is more graphically illustrated than in the previous table.

Of the positive tests tabulated, only one was positive in 24 hours. The remainder were positive in 48 hours. The one test confirmed on Endo's medium was the test that was positive in 24 hours. In Period I only about 20 per cent of the Endo-plate cultures gave gas when reinoculated into lactose-broth fermentation tubes, and in Period IV that percentage decreased to less than 10 per cent. It frequently happened that there was no growth at all on Endo plates streaked from positive gas tubes. Thus, most of the positive tests would be classified as false presumptives.

The colonies on the Endo plates that did not ferment lactose on reinoculation were dead white, raised, circular, and moist but not mucoid. They did not resemble *E. Coli, A. aerogenes,* or the coliform intermediates commonly encountered in raw-water supplies. They were Gram-negative rods that looked like coliform bacteria when examined microscopically. A number of these cultures have been collected and are being studied further for identification and behavior.

The raw water from the intake reservoir always can be depended upon to yield a considerable percentage of the false presumptive tests, and no doubt this is the source of the bacteria responsible for the false presumptive tests from the treated water. The monotonous regularity of the failure of the gas-positive cultures to confirm led to occasional checks of the Endo's medium with known members of the coliform group. Results were always satisfactory.

Table 4 shows the rate of application of chlorine and ammonia and the residuals from the time the treatment was begun through 1943. The gas tanks stand on platform scales and are weighed from time to time. The residuals were determined from samples taken at a station about fifteen hundred feet from the chlorinating plant. No

TABLE 4.—CHLORINE-AMMONIA APPLICATION

Period	Date	Cl_2—lb.	NH_4—lb.	Ratio	Residual Chlorine—p.p.m.
	1942				
II	Sept.	99.75	16.50	6.0:1	0.20
	Oct.	129.00	25.00	5.2:1	0.15-0.20
	Nov.	127.50	19.50	6.5:1	0.15-0.18
	Dec.	78.50	24.50	3.2:1	0.10
	1943				
III	Jan.	74.75	26.75	2.8:1	0.08
	Feb.	69.50	34.50	2.0:1	0.10-0.15
	Mar.	64.75	26.00	2.5:1	0.10-0.15
	Apr.	63.00	22.75	2.8:1	0.10
	May	84.00	27.00	3.1:1	0.10
	June	93.25	29.00	3.2:1	0.15
	July	71.75	27.00	2.7:1	0.10-0.15
	Aug.	103.30	36.75	2.8:1	0.10-0.15 (½) 0.30
IV	Sept.	111.50	52.75	2.1:1	0.035 (½) 0.025
	Oct.	112.00	63.25	1.7:1	0.25 (½) 0.20
	Nov.	141.00	65.50	2.2:1	0.30 (1/3) 0.10
	Dec.	91.25	27.25	3.4:1	0.18

plate counts or fermentation tests were made from this station. The data in this table are from the records of the Amherst Water Department. The ortho-tolidin method was employed for determining residuals. Determinations were made daily, but the mean values for the several months are presented in the table.

The data in Table 4 are grouped into the same time periods as were employed in Tables 2 and 3. Period I is not included because no ammonia was used before Period II. It will be observed that in Period I there was considerable fluctuation in the $Cl:NH_3$ ratio due to the fact that experimentation was necessary to arrive at a satisfactory dosage from the standpoint of the effect on the taste of the water. In the late part of Period III and the early part of Period IV the residual was increased in the effort to control the increased number of presumptive tests that began to appear. This treatment was not effective, so in November of Period IV the residual was reduced.

COMMENTS

It is not the purpose of this report to approve or condemn the chlorine-ammonia treatment of water, nor does the author wish to have his remarks interpreted as a criticism of the treatment. The value of chlorine-ammonia for treating water has been reported by a number of investigators, some of whose contributions are listed at the end of this paper.

It is, perhaps, to be expected that a small supply such as that in Amherst will offer problems that may not occur or that may be more easily overcome in a large city system. The Amherst water supply is a relatively small surface supply like that of many of the smaller New England and Atlantic seaboard communities. At certain seasons of the year the water has a high organic content, and there is no provision for its removal by sedimentation or filtration. This naturally hinders satisfactory control and uniform application of either chlorine or chlorine-ammonia.

The false presumptive tests should occasion no particular alarm so far as the health of the community is concerned. These tests, however, do make for an unsatisfactory record, and poorly informed persons having access to the records may easily draw erroneous conclusions and make much unnecessary trouble for responsible officials of a water department or company. There is no question that such a condition should be corrected.

The author feels that a number of studies like those here reported, made in different places and under different environmental conditions, should furnish information that will improve the value of the chlorine-ammonia treatment for small municipal water supplies and make it possible to avoid or correct difficulites that may be encountered.

SUMMARY

1. Plate counts from water treated with chlorine-ammonia did not appear to be much influenced by the treatment. There was

some increase in aerobic sporulating bacilli, but no significance is indicated.

2. About one year after the chlorine-ammonia treatment was instituted the numbers of positive presumptive tests began to increase substantially These tests did not confirm on Endo's medium, and positive refermentation tests were obtained from less than 10 per cent of the positive gas tubes.

3. The conclusion is that most of the presumptive tests are false presumptives; and that chlorine-ammonia treatment appears to be responsible, under the conditions locally existent, for these false presumptives and for their increase.

4. Further study is being made to determine the organisms responsible for the false presumptive tests, and the cause of their increase.

ACKNOWLEDGMENTS

The author wishes to acknowledge the valuable and willing assistance of George C. Brehm, Superintendent, and John A. White, Foreman, of the Amherst Water Department. Mr. Brehm furnished information, collected some of the samples, and generally made the facilities of his organization available. Mr. White collected most of the samples.

Acknowledgment is also due Norman Alexander, graduate student in bacteriology at Massachusetts State College, who did some of the bacteriological work for the study.

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FLUORIDES IN WATER IN RELATION TO DENTAL DECAY

BY BASIL G. BIBBY*

[*Read January 24, 1944.*]

Five, ten, or even twenty years ago a discussion on the subject of drinking water in relation to dental decay would have been regarded as old fashioned. Before the turn of the century everyone concerned with the prevention of dental disease, and many other disabilities, was interested in the possible relationship of water to health. At that time there was a great deal of work done on the subject, and several investigators reached the conclusion that dental decay was the result of drinking soft waters. That conclusion was soon shown to be unwarranted, and for thirty years or more investigators have been looking in other directions.

Within the last ten years a great deal of work has been done by the United States Public Health Service in trying to determine the cause of a disfiguring condition of the teeth which is found in certain areas of this country and many other parts of the world. The condition I refer to is "mottled enamel" which causes the teeth of children in certain communities to be brown and black instead of pearly white as we like to see them. It was finally found that mottled enamel was caused by fluorine in the drinking water, and that anything above 1 p.p.m. of fluorine resulted in its appearance in an appreciable percentage of the children. To correct this many communities sought fresh sources of water. It was found that when the fluorine content of the water was reduced below 1 p.p.m. this unsightly enamel ceased to occur.

As a side observation in these studies of mottled enamel, it was noted that those children who showed a mild degree of mottling had less dental decay than those who had been using fluorine-free drinking water and whose teeth showed no signs of mottled enamel. This finding led to a further series of studies, the first of which was published about four years ago. Briefly, these show that in communities where there are one or more parts per million of fluorine in the water there is only about half as much dental decay as in regions where the water is fluorine-free. This obviously suggested that the fluorine was working in some way to prevent dental decay.

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Other evidence that fluorine could act to prevent dental decay came from laboratory research. It was found that a condition resembling dental decay in rats could be prevented by adding fluorine to their water supply; that is simply by adding a little fluoride to the rats' drinking water. It did not work if the fluoride was injected into the blood stream or fed by stomach tube. It was also discovered that there was a chemical difference between caries-resistant teeth and caries-susceptible teeth. Those teeth which succumbed to dental decay were found to have less fluorine in the enamel than those which were resistant to it, there being about 69 p.p.m. in the former as compared to 111 p.p.m. in the latter.

In short, evidence from three fields of study indicated clearly that fluorine worked in some way to prevent dental decay.* This naturally gives rise to the question, "How can these findings be used for the benefit of mankind?" The first and most obvious answer is that of adding fluorides to the water supply. On the basis of the epidemological evidence just cited this procedure should enable us to reduce dental decay to about half what it otherwise would be.

The question of whether fluorine or other chemicals should be added to water for the purpose of reducing dental decay is one which has to be weighed carefully. More than any other group water works engineers will realize that such a step cannot be taken too lightly. Failure to consider all possibilities might give rise to all sorts of complications.

The first point to be considered in relation to adding fluorine to the water supply is whether there is any real need for considering such a procedure. Is tooth decay of sufficient social significance to justify meddling with the water? I will answer that question as a dentist and run the risk of being accused of having a biased point of view. I claim that dental caries is important enough to justify

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*For full reviews on this subject consult J. F. Volker and B. G. Bibby, Medicine 1941, **20**:211. or B. G. Bibby, Journ. Am. Dent. Ass'n 1944, **31**:228.

any such step. I will go further and say that the importance of dental decay is not sufficiently realized. As the commonest affliction of childhood and adolescence it gives rise to a great many undesirable sequelae of a physical and psychological sort. In addition it is a disease of great economic importance. For instance, in Massachusetts alone more than $20,000,000 is spent every year for the repair of dental decay. That $20,000,000 does not take care of the teeth of all the people; it takes care of the teeth of only 20 per cent of them. If everyone had the dental service which we dentists feel they should have, Massachusetts alone would spend $100,000,000 a year. It is not commonly realized that of every dollar spent in this country for the preservation or restoration of health (the cost of hospitals; the maintenance of city, state and federal health services; the purchase of drugs; the payment of nurses and physicians' salaries, etc.) seventeen cents goes to taking care of the teeth. According to figures from the American Medical Association actual payments to dentists are forty per cent of those received by physicians. In other words, dental decay is a disease of the greatest economic importance.

At this time we should be particularly conscious of the need for doing something about the teeth because of the complications that arose in the early days of the war, when the Nation was trying to equip itself with a completely physically fit Army. In Vermont, for instance more than 100 out of every 1,000 selectees who were examined were rejected because of dental defects. The same thing happened in the Civil War and also in the last World War. More than a quarter of the Nation's dentists are now in the armed forces trying to keep our fighting men fit. The reason for this concern for the teeth is that at one time or another dental disease has been a grave threat to the efficiency of armies. In the Boer War in South Africa, for instance, one-tenth of the soldiers that were sent to South Africa were invalided back to England because of dental trouble of one sort or another.

Dental decay is particularly important in the Northeastern United States. In New England we have almost twice as much of it as in any other part of the country. I can quote Civil War figures, World War I figures or World War II figures to prove this point.

Figures from all three sources are surprisingly similar. I have already mentioned that in the First World War 102 men out of every 1,000 were rejected for dental defects in Vermont. As we go south and west from New England the number of dental rejectees declines. In New York, Pennsylvania, and New Jersey from 29 to 52 per 1,000 were rejected for dental defects. Farther south and west the rejection figure drops to less than 20 per 1,000. In Arkansas and Kansas rejections were 2.9 and 3.9 per 1,000. Obviously there is a vast difference in the susceptibility to dental decay in the various parts of the United States. For that reason if anything can be done to prevent dental decay by treating the water, those of you who are in charge of water supplies in New England will be the ones who will be called upon to do something about it. Before long the question of whether fluorine should be added to the water is going to become an acute problem for some of you who are responsible for deciding these matters.

While I have made a fairly strong case for considering the possibility of adding fluorides to the water supply, I fully realize that such a step would give rise to special problems. There are a number of them. First, if fluorides are added to the water, the major beneficial effect will not show itself for eight or ten or even more years. Second, a large part of the population does not use public water supplies. Actually, I believe that about half the people of the United States use private sources rather than communal. As a result fluorination of water is only going to affect half of the population, and less than half in rural areas. Third, additions of fluorine may interfere with certain industrial processes. The glassware industry might suffer; brewing would probably be adversely affected; undoubtedly there are other industries in which difficulties would appear. Fourth, technical complications may appear in the water distribution systems. Possibly reactions would occur between freshly added fluorides and the iron of the pipes or other mineral constituents of the water. Such possibilities would vary according to the chemical content of the water or according to the various supply systems in use. However, since you know much more about these possibilities than anyone else, I obviously do not need to expand them. Fifth, the margin of safety between the point at which prevention of dental decay will result and the point at which manifestations of excessive intake of fluorine might appear is rather too narrow to ensure freedom from undesirable effects. Because there are variations in the water intake of different people; because there are undoubtedly variations in the absorption of fluorine into the system in different individuals, depending upon metabolic or nutritional factors; and because there are probable differences in the availability of fluorine from different water supplies a water consumption which does not produce any effect in one person may conceivably produce mottled enamel or other signs of fluorosis in another. The problem is to determine the proper amount of fluoride to add to the water. There must be enough to be effective but not enough to be dangerous. We do not know enough to be definite on this point. As far as we can go is to say that it is relatively certain that by adding 1 p.p.m. of fluorine to the water we could reduce dental caries by approximately one-half without more than ten per cent of the users showing any obvious signs of mottled enamel. This conclusion is based mainly on information from areas where the basic water supply is different from that in New England. In New England we have a much lower mineral content than in these other areas and it is possible that we may run into special problems if we add fluorides to soft waters such as ours.

In this matter, as on all others, there are two sides to the question. There is very good reason for doing something in the direction of adding fluorine to the water, but there are certain reasons why it might be wise to proceed carefully in this direction. It is probable, however, that the normal "administrative lag" will supply all the delay that is necessary and that it is not too soon to start considering putting this new approach to caries control into effect.

The foregoing considerations lead logically to the question of whether there is any alternative way of using fluorides besides adding them to the water supply. The answer to this question depends upon an understanding of the mechanisms by which fluorine works to prevent dental decay. Is it the result of the fluorine being swallowed, absorbed into the blood stream and passing into the teeth, or does it act in some other way? There are good grounds for thinking that the swallowing of the fluoride and its deposition in the teeth is not the complete answer to the question. I shall give just a few of the reasons for believing this.

When fluorine is ingested in the early years of life, and then not taken after the teeth are formed, it does not give as full a reduction of dental caries as when it is taken throughout life. Another reason for thinking that the deposition of the fluorine in the teeth during their formative years is not the whole answer as given by a consideration of the effect of fluoride on different teeth. The first molars are calcified between birth and six years of age and so are the central incisors, but in spite of this the reduction of decay in the incisors is seven or eight times as marked as it is in the molars. If caries reduction was the result of fluoride being deposited in the teeth while they were being developed then these two types of teeth should show the same degree of caries reduction. Since this is not the case other explanations must be sought.

An alternative possibility is that the fluorine passes from the intestine into the blood and is secreted through the saliva into the mouth, acting there to prevent decay. This explanation is unsound because it can be shown that no fluorine passes into the sailva. The analysis of the saliva of children drinking water containing 1.8 p.p.m. of fluorine failed to show measurable quantities of fluorine. In addition, experiments with radioactive fluorine have demonstrated that this element does not pass into the saliva as do the other halogens. Animal experiments offer further evidence on this point, for even after surgical removal of the salivary glands from rats and the consequent absence of saliva, fluorine in these animals' drinking water is still effective in preventing dental caries.

A further possibility is that fluorine from the water may be retained in the mouth and act there to interfere with the mechanisms of tooth decay. We have carried out tests which show that sugar does not break down to acid when fluorine is present in minute quantities. Consequently fluorine in the mouth would prevent acid formation, and since we believe that decalcification with acids is the only way of destroying tooth enamel it seems obvious that if fermentation in the mouth can be reduced we have gone a long way towards preventing dental decay. However, it has yet to be demonstrated that sufficiently high concentrations of fluorine persist in the mouth for a sufficiently long period of time to produce effects of the sort indicated.

A fourth possibility is that fluorine in the water reacts with the tooth surface in some way to make it more resistant to the action of the decalcifying acids. It has been known for some time that the solubility of certain phosphates is influenced by their fluorine content, and since we know that the enamel of caries-resistant teeth has more fluorine than does that of caries-susceptible teeth, there is some reason to believe that an increase in the fluoride content of the enamel would reduce dental caries. How could an increased fluorine content of tooth enamel result from fluorine in the drinking water? We have already indicated that the idea that it is deposited during the formation of the tooth does not provide an adequate explanation. Is it possible that there could be a direct combination between the tooth and the fluorine from the water supply? The fact that bone or calcium phosphate can be used as a filter to remove fluorine from the water when there is enough fluorine in the water supplies to produce mottled enamel suggests that there would be a similar reactivity between fluorine of the water and the calcium phosphate which is the principal constituent of tooth enamel. Since the basic inorganic molecule of bone and dental enamel are the same, it is natural to expect that such a reaction would occur. Actual laboratory tests show that teeth immersed in fluorine-containing solutions do take up relatively large quantities of fluorine. It can also be shown that by dipping a tooth in a fluoride solution it becomes less soluble in acid. The solubility of enamel or dentin powder can be reduced by 40 to 50 per cent by treatment with fluoride solutions. In view of these findings it would seem possible to explain the added resistance of the tooth to decay to a reaction between the fluorine of water and the enamel on the outside of the tooth.

There are several good clinical reasons for thinking that that is a correct explanation. I will give one of them. You will notice that in drinking water it is the front teeth that get in the water and that the posterior teeth have a very limited contact with it. Consequently if a direct reaction between the teeth and the fluorine in the water is one of the principal means by which the teeth are made resistant to decay it would be natural to expect a more marked reduction of caries in the upper anterior teeth than elsewhere in the mouth. Such indeed is the case. It will be recalled that we noted earlier in this paper that the reduction in the incisors was seven or eight times that which occurred on the molars.

Having decided that caries reduction is brought about largely as a result of a direct reaction between the fluorine of water and the teeth, let us return to our consideration of providing a means of using fluorine to reduce dental decay other than by adding it to the water supplies. Since fluorine acts in the way it does isn't it possible that we could reduce dental decay by simply painting the teeth with a fluoride-containing solution as well as by putting the fluorine in the water supply? Tests have shown that this can be done. There are now three series of results published which show that painting the teeth with fluoride solutions will reduce dental decay by approximately forty per cent. Three paintings a year, which I gave to children's teeth in Brockton produced such a result as did somewhat different tests in Minnesota and Indiana.

What then, is the best way to use fluorine? Should dentists paint it on the teeth, should dental hygienists or patients themselves use it on the teeth, or should it be put in the water supply? There are arguments on both sides. The tooth painting is time-consuming and money-consuming. Only those who can be persuaded to take advantage of it will benefit by it. By putting it in the water supply everyone in the water supply area will receive benefits whether they do anything about it or not. Are we morally justified in forcing therapy of this sort upon people who do not want it? Health authorities have a moral obligation to do something practical to prevent any disease as socially and economically important as dental decay.

It seems to me that the decision as to which procedure should be followed will be determined largely by the demands of the public. These demands will be made both on the dental profession and on the water works engineers but it will be you, the men who are responsible for the water, who will have to carry the principal weight of the argument on anything touching on treatment of the water supplies. I do not offer or attempt to offer a plan or policy for you. I am pleased enough to have the opportunity of "passing the buck" to you and letting you decide your part of the question alone. I would suggest, however, that you give the various aspects of the problem due thought because sooner or later you will have to make decisions on these matters.

DISCUSSION

PRESIDENT CLARK. I think we should ask Dr. Bibby why he does not put it into toothpaste?

DR. BIBBY. The reason for not advocating use in dentifrices is that the Federal Food & Drug Administration does not permit the inclusion of fluorides in toothpastes. Until such time as we can prove that they are really beneficial fluoride toothpastes will not be within the law.

FRANCIS H. KINGSBURY.* I would like to ask Dr. Bibby if, as far as he knows, there is any public water supply in the United States that is being artificially treated by the addition of fluorine for this purpose.

DR. BIBBY. The latest information I have on that point is that in New York State there is a program, which has been incubating for more than a year, which was recently before the Budget Committee of New York State for final approval, with approval to be expected. The proposal is to add sodium fluoride to the water supply of one town, a town of about thirty thousand people, for a period of about ten years, and not add it to the supply of a comparable town, and to make continuous studies on the activity of dental decay. I think that they will have the studies underway within the next few months. They have calculated that the fluoride, together with the apparatus and everything else, will cost 7½ cents per person per year.

In Michigan there is a town which is changing its water supply from one containing no fluorine to one that contains one part or more per million of fluorine. It is a natural source of fluorine in this instance. There the public health department proposes to make a continuous study of the effect of the increased fluorine content of the water supply.

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*Boston, Mass.

We have been approached by the people of one or two New England communities asking us to help them work out plans for supplementing their water supplies with fluorine. As things stand I don't see any likelihood of any immediate developments in this vicinity. I would like to have you know that my personal interest in this approach is such that if you New England water specialists are interested in such a proposition, I would love to have the opportunity of coöperating with them. I think it should be tried here and in New England where dental decay is so much worse than in the rest of the country.

DONALD C. CALDERWOOD.† How expensive is the so-called painting on by the dentist?

DR. BIBBY. That has not been done on a private practice basis. It has been done only experimentally. I am afraid I could not calculate the probable expense for a reasonable return to the dentist. It should be relatively inexpensive. The procedure is no more time-consuming and can be a great deal less time-consuming than the ordinary dental prophylaxes which are given. I should feel that probably the most economical way of doing it would be to have it done by the hygienists or some group of dental assistants. If done on a group basis in the schools it should not amount to more than 50 cents or so a treatment. A private dentist could not give treatment for such a low fee.

GEORGE E. RUSSELL.‡ Is it true that the statutes would prevent us putting fluorine in toothpaste and chewing gums, or putting it in the drinking water supply of a city or town?

DR. BIBBY. I don't know the regulations in regard to water supplies. I know there are inhibitions against putting it into chewing gum and other products. That is also true of dentifrices and foods. Possibly water supplies come under a different department in Washington and may be governed by different rules.

PRESIDENT CLARK. I might ask Mr. Kingsbury to answer that question.

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†Nashua, N. H.
‡Arlington, Mass.

Mr. Kingsbury. As near as we can figure it out in Massachusetts thus far, we would prefer to learn considerably more about it before we approve of it being put in a water supply. While in the southwest and south some characteristics of the water might protect against mottled enamel with 1 p.p.m. fluoride, we here in New England, with the smaller amount of solids in the water, feel that 1 p.p.m. might not be the threshold and that some town that started that proposition might find itself in an argument with some of its consumers. We do not think we know enough about it yet. We are looking to Dr. Bibby and others to give us more information.

There was a question asked me today about the disinfecting qualities of fluorine, and I talked with the government chemists, and they indicated that in the form in which fluoride would be added disinfection would not be important. I checked with Dr. Bibby that the prevention of decay is not the prevention of bacterial action, but the prevention of chemical action of the acid reacting with the enamel.

In one town there has been some talk, "Why chlorinate, and why establish chlorinating apparatus, because it will soon be superseded and we will be putting in fluorine apparatus?" I think they are quite a bit ahead of the game.

President Clark. I would like to ask Dr. Bibby as to how it would be put into the water, whether as a salt?

Dr. Bibby. I understand that there is something called a dry feed apparatus. This I believe could be used to put fluoride in as a dry powder. There are publications dealing with this aspect of the problem to which I can refer you if you wish it. Reading the publication as a layman, it looks very simple.

President Clark. I want to thank Dr. Bibby for his very interesting talk. I think it is a subject that requires a lot of study.

PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS AND MANUAL OF RECOMMENDED WATER SANITATION PRACTICE*

STANDARDS ADOPTED BY THE PUBLIC HEALTH SERVICE SEPTEMBER 25, 1942, FOR DRINKING AND CULINARY WATER SUPPLIED BY COMMON CARRIERS IN INTERSTATE COMMERCE

[*Superseding Standards adopted June 20, 1925*]

UNITED STATES PUBLIC HEALTH SERVICE,
Washington, D. C., September 25, 1942.

ADOPTION

The Public Health Service hereby adopts the standards of purity for drinking water recommended by the Advisory Committee on Revision of the 1925 Drinking Water Standards, appointed by the Surgeon General in February 1941.

These Standards are adopted for use in the administration of the Interstate Quarantine Regulations as they relate to the drinking and culinary water supplied by common carriers in interstate commerce. The manual of recommended water sanitation practice is intended to serve as a guide to the reporting agency and not as a part of the official Standards which must be complied with to obtain certification of the water supply.

In the future common carriers will be required to furnish drinking and culinary water for passengers and crews in interstate traffic which will conform to these standards.

(S) THOMAS PARRAN,
Surgeon General, United States Public Health Service.

Approved: Dec. 3, 1942
(S) Watson B. Miller,
Acting Administrator, Federal Security Agency.

PREFACE TO THE 1925 EDITION

The preface of the 1925 Drinking Water Standards is presented below and represents the ideas and report of the Advisory Committee which assisted in the preparations of those Standards. This material is presented as an historical background upon which some of the findings of the present committee have been based.

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*Reprinted with the permission of the Surgeon General, U. S. Public Health Service, from the Public Health Reports, January 15, 1943; Pages 69-111. (Reprint No. 2440 from the Public Health Reports.)

In recommending the adoption of these Standards the Advisory Committee submitted a report discussing the requirements as follows:

REPORT OF THE ADVISORY COMMITTEE ON OFFICIAL WATER STANDARDS[1]

The task referred to this committee by the Surgeon General of the Public Health Service is to formulate definite specifications which may be used by the Public Health Service in the administrative action which it is required to take upon the supplies of drinking water offered by common carriers for the use of passengers carried in interstate traffic. The recommendations submitted apply, therefore, only to this special case, and are not proposed for more general application.

Since the purpose of the supervision which the Public Health Service exercises over these water supplies is to safeguard the health of the public, the examinations and specific requirements herein proposed have reference chiefly to forming a judgment of safety, and are designed especially to afford protection against the most serious danger which is associated with water supplies; namely, that of infection with typhoid fever and other diseases of similar origin and transmission. Less emphasis has been placed upon physical and chemical characteristics affecting the acceptability of water with respect to appearance, taste, and odor, because these are matters of less fundamental importance and because, in actual experience, the water supplies which come under consideration, if satisfactory from the standpoint of safety, will usually be found satisfactory with respect to physical and chemical characteristics.

The first step toward the establishment of standards which will insure the safety of water supplies conforming to them is to agree upon some criterion of safety. This is necessary because "safety" in water supplies, as they are actually produced, is relative and quantitative, not absolute. Thus, to state that a water supply is "safe" does not necessarily signify that absolutely no risk is ever incurred in drinking it. What is usually meant, and all that can be asserted from any evidence at hand, is that the danger, if any, is so small that it cannot be discovered by available means of observation. Nevertheless, while it is impossible to demonstrate the absolute safety of a water supply, it is well established that the water supplies of many of our large cities are safe in the sense stated above, since the large populations using them continuously have, in recent years, suffered only a minimal incidence of typhoid fever and other potentially water-borne infections. Whether or not these water supplies have had any part whatsoever in the conveyance of such infections during the period referred to is a question that cannot be answered with full certainty; but the total incidence of the diseases has been so low that even though the water supplies be charged with responsibility for the maximum share which may reasonably be suggested, the risk of infection through them is still very small compared to the ordinary hazards of everyday life.[2]

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[1] Pub. Health Rep., 40:693-721 (April 10, 1925).

[2] This evidence actually proves only that the water supplies in question have been generally "safe" in

The committee has, therefore, taken this better class of municipal water supplies as its standard of comparison with respect to safety and proposes, as a fair objective, that the water supplies furnished by common carriers to passengers in interstate traffic be of comparable safety. As regards protection of the traveling public, such a standard is fair, since it implies that the use of the water supplied to them in travel shall not add to the almost negligible risk which is ordinarily incurred at home by those who habitually use water supplies of somewhat better than average quality. From the standpoint of the carriers also, this standard is believed to be fair and reasonable, since it refers to water supplies which are actually obtainable in all sections of the country and from a great variety of sources.

The next and principal task of the committee has been to set up objective requirements which will conform to this general standard of safety; that is, requirements which will ordinarily be fulfilled by the municipal supplies of epidemiologically demonstrated safety which constitute the standards of comparison, but will exclude supplies of less assured safety. Since there is no single and measurable characteristic of water supplies which bears any known and constant relation to actual safety, the standard recommended is composite, including certain requirements relative to the source and protection of the water supplies in question as indicated by a careful sanitary survey, and certain other requirements relative to bacterial content as shown by standard tests.

It is anticipated that little objection will be raised to the requirements laid down as to source and protection, at least to their general intent, because they are based upon well recognized principles of sanitary engineering, and because they are necessarily stated in general terms which imply a rather broad consideration of each supply from all angles and the exercise of discretion in forming an ultimate judgment of its fitness. The bacteriological standard, on the other hand, is stated in definite quantitative terms. This is unavoidable if such a standard be included at all, since the methods of bacteriological examinations are quantitative and yield results in the definite terms used in the standard. However, in view of the well-recognized principle that the significance of bacteriological examinations is variable, and must be interpreted with due regard to all other facts known about the particular water supply in question, the objection may be raised that a rigid application of this standard will arbitrarily exclude a considerable number of water supplies which conform to all other requirements and which competent opinion will consider to be quite safe. The validity of this criticism is recognized, but it is not considered of sufficient force to require or justify the lowering of the bacteriological standard proposed. This viewpoint appears proper when it is recognized that the definite terms of bacteriological quality in which this standard is expressed represent only agreement as to safety,

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the past during the period of low prevalence of infection. The likelihood that they will continue to be equally or more safe in the future must, of course, be reckoned from other considerations, such as the probability of future change in the pollution of their watershed, the character and consistency of their protection, etc.

and not as to limiting values beyond which demonstrable or even presumptive danger lies. Between the point on which the committee is in agreement as to the assured safety of water supplies and the point at which agreement could be reached as to their dangerous quality is a wide zone. Within the zone lie many water supplies which, if considered in the light of available evidence from all angles, are believed to be as safe as other supplies which conform to all the bacteriological requirements.

The committee, therefore, considers it preferable to recommend that in actual practice the bacteriological standard be applied, as are other requirements, with some latitude; in other words, that supplies which, on rigid inspection, are found to be satisfactory in other respects but fail to meet the bacteriological standard, may be accepted in the discretion of the certifying authority. In view of the character of the personnel entrusted with the responsibility for investigation and administrative action, the committee feels assured that this procedure is preferable to the alternative of rigid and automatic application.

PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS

STANDARDS ADOPTED BY THE UNITED STATES PUBLIC HEALTH SERVICE, FEDERAL SECURITY AGENCY, SEPTEMBER 25, 1942, FOR DRINKING AND CULINARY WATER SUPPLIED BY COMMON CARRIERS IN INTERSTATE COMMERCE

(Superseding Standards adopted June 20, 1925)[1]

In recommending the adoption of the revised Standards the Advisory Committee submitted a report discussing the requirements as follows:

REPORT OF THE ADVISORY COMMITTEE ON OFFICIAL WATER STANDARDS

The requirements for drinking (and culinary) water provided by common carriers for the use of passengers carried in interstate traffic, commonly known as the "Treasury Department Drinking Water Standards," were last revised in 1925, and published in the Public Health Reports of April 10 of that year. Since that time many improvements in water supply practice have been adopted with resulting increased uniformity of quality and safety to the consumer. Moreover, the Public Health Service, in recent years, has been requested by the American Public Health Association, the American Water Works Association, and the American Chemical Society to review the 1925 Standards. Accordingly, the Public Health Service has undertaken a revision of the Standards in order to have them conform more closely to current requirements for water supplies of attainable safety and potability.

To carry out such a revision the Surgeon General of the Public Health Service, on February 27, 1941, appointed the undersigned special Advisory Committee composed of representatives of various Federal organizations and scientific associations and including several members at large. A smaller subcommittee of Public Health Service officers was designated to prepare tentative suggestions for the consideration of the Advisory Committee.

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[1] Pub. Health Rep., 40:693-721 (April 10, 1925).

After thorough consideration, the advisory committee recommends the adoption of the revisions as set forth in the text herewith submitted. The principal changes now proposed are:

(1) A distinct separation of the text into: (*a*) that portion containing the statement of the Standards, and (*b*) that portion constituting a recommended manual of water works practice representing the judgment of the technical subcommittee composed of officers of the Public Health Service. This portion of the text is intended to serve as a guide to the reporting agency and should not be considered as indicating additional requirements to be met for certification of the water supply.

(2) In the bacteriological section the use of 5-10 ml. portions or of 5-100 ml. portions is made optional; a minimum number of samples is to be examined monthly, the number depending upon the population served; the laboratories in which bacteriological examinations are made and the methods used in making them are subject to inspection at any time by the designated representative of the certifying authority.

(3) Concentration limits for lead, fluoride, arsenic, and selenium are included as part of the Standards and their presence in excess of the limits stated shall constitute ground for rejection of the supply. Limits in concentration that should not be exceeded, where other more suitable supplies are available, are given for copper, iron and manganese together, magnesium, zinc, chloride, sulfate, phenolic compounds, total solids, and alkalinity.

(4) The results of recent studies on the potential pollutional hazards existing in the water supply systems of our communities due to faulty plumbing practices, cross-connections, interconnections, etc., as well as the pollutional hazards which are due to faulty water plant and distribution system operational practices, any or all of which may jeopardize the safety of the water in the distribution system, have been adjudged as being of prime importance in the consideration of the requirements of these Standards. The utmost care and consideration have been given to the inclusion of those provisions which would serve to detect possible contamination arising in the distribution system and thus lead to its correction and further safeguarding of the traveling public.

The Committee believes that, in general, water supplies to be eligible for certification should meet all (sanitary, chemical, and bacteriological) requirements of the Standards and that definite failure to meet any one of them should be ground for rejection or provisional certification, according to the judgment of the certifying authority. However, it is realized that the statement of an official standard of drinking water quality, to be generally applicable, must be interpreted reasonably. The Committee has attempted to take into consideration all aspects of the problem. It offers these Standards with the recommendation that the judgment and discretion of the certifying authority be exercised in their application.

MEMBERSHIP OF ADVISORY COMMITTEE ON REVISION OF THE DRINKING WATER STANDARDS[1]

Joseph W. Mountin, *Chairman, Assistant Surgeon General, States Relations Division, U. S. Public Health Service, Washington, D. C.*

J. K. Hoskins, *Secretary, Senior Sanitary Engineer, Chief, Sanitation Section, U. S. Public Health Service, Washington, D. C.*

REPRESENTATIVES OF FEDERAL ORGANIZATIONS

Food and Drug Administration: J. W. Sale, Senior Chemist, Food Division, Federal Security Agency, Washington, D. C.

U. S. Geological Survey: W. D. Collins, Chemist in Charge, Quality of Water Division, Department of the Interior, Washington, D. C.

REPRESENTATIVES OF SCIENTIFIC ASSOCIATIONS

American Chemical Society: A. M. Buswell, Chief, Illinois State Water Survey Division, Urbana, Ill.

American Public Health Association: Abel Wolman, Professor of Sanitary Engineering, Johns Hopkins University, Baltimore, Md.

American Society of Civil Engineers: Arthur E. Gorman, Engineer of Water Purification, Bureau of Engineering, Department of Public Works, Chicago, Ill.

American Water Works Association: Charles R. Cox, Chief, Bureau of Water Supply, State Department of Health, Albany, N. Y.

Association of American Railroads: R. C. Bardwell, Superintendent, Water Supply, Chesapeake and Ohio Railroad, Richmond, Va.

Conference of State Sanitary Engineers: Arthur D. Weston, Director and Chief Engineer, Division of Sanitary Engineering, State Department of Health, Boston, Mass.

Society of American Bacteriologists: A. C. Hunter, Principal Bacteriologist, Food and Drug Administration, Federal Security Agency, Washington, D. C.

MEMBERS AT LARGE

Herman G. Baity, Professor of Sanitary Engineering, University of North Carolina, Chapel Hill, N. C.

R. E. Buchanan, Director, Agricultural Experiment Station, Iowa State College, Ames, Iowa.

R. F. Goudey, Sanitary Engineer, Bureau of Water Works and Supply, Los Angeles, Calif.

TECHNICAL SUBCOMMITTEE, OFFICERS OF THE PUBLIC HEALTH SERVICE

J. K. Hoskins, Senior Sanitary Engineer, Chief, Sanitation Section, States Relations Division, Washington, D. C. (Secretary).

R. E. Tarbett, Senior Sanitary Engineer, Washington, D. C.

H. W. Streeter, Senior Sanitary Engineer, Stream Pollution Investigations, Cincinnati, Ohio.

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[1] Official positions indicated are as of February 27, 1941, when the Committee was organized.

C. T. Butterfield, Principal Bacteriologist, Stream Pollution Investigations, Cincinnati, Ohio.

C. C. Ruchhoft, Principal Chemist, Stream Pollution Investigations, Cincinnati, Ohio.

Lawrence T. Fairhall, Principal Industrial Toxicologist, National Institute of Health, Bethesda, Md.

PART I—PUBLIC HEALTH SERVICE STANDARDS

1. DEFINITION OF TERMS

For the purpose of these Standards the terms designated herein below shall be defined as follows:

1.1. *Adequate protection by natural agencies* implies various relative degrees of protection against the effects of pollution in surface waters; dilution, storage, sedimentation, the effects of sunlight and aeration, and the associated physical and biological processes which tend to produce natural purification; and, in the case of ground waters, storage in and percolation through the water bearing material.

1.2. *Artificial treatment* includes the various processes commonly used in water treatment, both separately and in combination, such as storage, aeration, sedimentation, coagulation, rapid or slow sand filtration, chlorination, and other accepted forms of disinfection. Rapid sand filtration treatment is commonly understood to include those auxiliary measures, notably coagulation and sedimentation, which are essential to its proper operation.

1.3. *Adequate protection by artificial treatment* implies that the method and degree of elaboration of treatment are appropriate to the source of supply; that the works are of adequate capacity to support maximum demands, are well located, designed, and constructed, are carefully and skillfully operated and supervised by properly trained and qualified personnel, and are adequately protected against floods and other sources of pollution. The evidence that the protection thus afforded is adequate must be furnished by frequent bacteriological examinations and other appropriate analyses showing that the purified water is of good and reasonably uniform quality, a recognized principle being that irregularity in quality is an indication of potential danger. A minimum specification of good quality would be conformance to the bacteriological and chemical requirements of these Standards, as indicated in sections 3 and 4.

1.4. *Sanitary defect* means any faulty structural condition, whether of location, design or construction of water collection, treatment or distribution works, which may regularly or occasionally cause the water supply to be contaminated from an extraneous source, including dual supplies, by-passes, cross-connections, or intercorrections (backflow connections) or fail to be satisfactorily purified.

1.5. *Health hazard* means any faulty operating condition including any device or water treatment practice, which, when introduced into the water supply system, creates or may create a danger to the well-being of the consumer.

1.6. *Water supply system* includes the works and auxiliaries for collection, treatment, and distribution of the water from the source of supply to the free-flowing outlet of the ultimate consumer.

1.7. *The coliform group of bacteria* is defined, for the purpose of these Standards, as including all organisms considered in the coli-aerogenes group as set forth in the Standard Methods for the Examination of Water and Sewage, eighth edition (1936), prepared, approved, and published jointly by the American Public Health Association and the American Water Works Association, New York City. The procedures[1] for the demonstration of bacteria of this group shall be those specified herein, for:

(*a*) The completed test, or

(*b*) The confirmed test when the liquid confirmatory medium brilliant green bile lactose broth, 2 per cent, is used, providing the formation of gas in any amount in this medium during 48 hours of incubation at 37° C. is considered to constitute a positive confirmed test, or

(*c*) The confirmed test when one of the following liquid confirmatory media is used: crystal violet lactose broth, fuchsin lactose broth, or formate ricinoleate broth. For the purpose of this test, all are equivalent, but it is recommended that the laboratory worker base his selection of any one of these confirmatory media upon correlation of the confirmed results thus obtained with a series of completed tests, and that he select for use the liquid confirmatory medium yielding results most nearly agreeing with the results of the completed test.

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[1] This reference shall apply to all details of technique in the bacteriological examination, including the selection and preparation of apparatus and media, the collection and handling of samples, and the intervals and conditions of storage allowable between collection and examination of the water sample.

The incubation period for the selected liquid confirmatory medium shall be 48 hours at 37° C. and the formation of gas in any amount during this time shall be considered to constitute a positive confirmed test.

1.8. *The standard portion of water* for the application of the bacteriological test may be either:

(*a*) Ten milliliters (10 ml.) or

(*b*) One hundred milliliters (100 ml.)

1.9 *The standard sample* for the bacteriological test shall consist of five (5) standard portions of either:

(*a*) Ten milliliters (10 ml.) or

(*b*) One hundred milliliters (100 ml.) each.

In any disinfected supply the sample must be freed of any disinfecting agent within twenty (20) minutes of the time of its collection.[2]

1.10. *The certifying authority* is the Surgeon General of the United States Public Health Service or his duly authorized and designated representatives and the *reporting agency* shall be understood to mean the respective State departments of health or their designated representatives.

2. As to Source and Protection

2.1. The water supply shall be:

(*a*) Obtained from a source free from pollution; or

(*b*) Obtained from a source adequately purified by natural agencies; or

(*c*) Adequately protected by artificial treatment.

2.2. The water supply system in all its parts shall be free from sanitary defects and health hazards and shall be maintained at all times in a proper sanitary condition.

3. As to Bacteriological Quality

3.1. *Sampling.*—The bacteriological examination of water considered under this section shall be of samples collected at representative points throughout the distribution system.

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[2] In freeing samples of chlorine or chloramines, the procedure given on page 286 in the Standard Methods for the Examination of Water and Sewage, eighth edition (1936), paragraph A-1—option 1, or paragraph A-2 shall be followed.

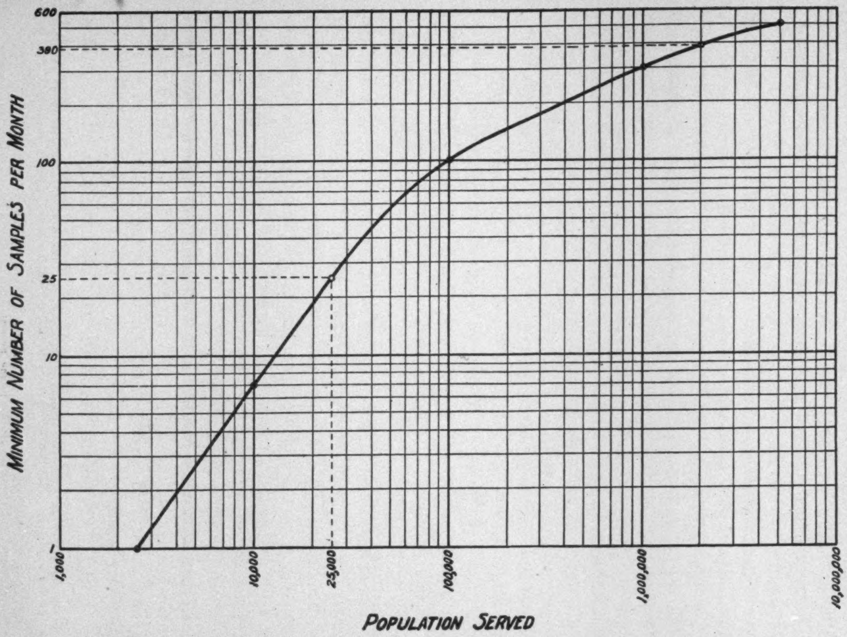

FIGURE 1.—Relation between minimum number of samples to be collected per month and population served.

The frequency of sampling and the location of sampling points on the distribution system should be such as to determine properly the bacteriological quality of the water supply. The frequency of sampling and the distribution of sampling points shall be regulated by the certifying authority after investigation of the source, method of treatment, and protection of the water concerned.

The minimum number of samples to be collected from the distribution system and examined by the reporting agency or its designated representative each month should be in accordance with the number as determined from the graph presented in Figure 1 of these Standards[3] which is based upon the relationship of population served and minimum number of samples per month:

Population served	*Minimum number of samples per month*
2,500 and under	1
10,000	7
25,000	25
100,000	100
1,000,000	300
2,000,000	390
5,000,000	500

The laboratories in which these examinations are made and the methods used in making them shall be subject to inspection at any time by the designated representative of the certifying authority. Compliance with the specified procedures, or failure to comply therewith, and the results obtained shall be used as a basis for certification, or refusal of certification, by the certifying authority in accordance with the application given below.

3.2. *Application.*—Applications 3.21 and 3.22 given below shall govern when ten milliliter (10 ml.) portions are used and applications 3.23 and 3.24 shall govern when one hundred milliliter (100 ml.) portions are used.[4]

3.21. Of all the standard ten milliliter (10 ml.) portions examined per month in accordance with the specified procedure, not more than ten (10) per cent shall show the presence of organisms of the coliform group.

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[3] For the purpose of uniformity and simplicity in application, the number of samples to be examined each month for any given population served shall be determined from the graph in accordance with the following:

For populations of 25,000 and under to the nearest 1.
For populations of 25,001 to 100,000 to the nearest 5.
For populations of 100,001 to 2,000,000 to the nearest 10.
For populations of over 2,000,000 to the nearest 25.

[4] It is to be understood that in the examination of any water supply the series of samples for any one month must conform to both of the above requirements, either 3.21 and 3.22 or 3.23 and 3.24, respectively.

3.22. Occasionally three (3) or more of the five (5) equal ten milliliter (10 ml.) portions constituting a single standard sample may show the presence of organisms of the coliform group, provided that this shall not be allowable if it occurs in consecutive samples or in more than

(*a*) Five (5) per cent of the standard samples when twenty (20) or more samples have been examined per month.
(*b*) One (1) standard sample when less than twenty (20) samples have been examined per month.

Provided further that when three or more of the five equal ten milliliter (10 ml.) portions constituting a single standard sample show the presence of organisms of the coliform group, daily samples from the same sampling point shall be collected promptly and examined until the results obtained from at least two consecutive samples show the water to be of satisfactory quality.[5]

3.23. Of all the standard one hundred milliliter (100 ml.) portions examined per month in accordance with the specified procedure, not more than sixty (60) per cent shall show the presence of organisms of the coliform group.

3.24. Occasionally all of the five (5) equal one hundred milliliter (100 ml.) portions constituting a single standard sample may show the presence of organisms of the coliform group, provided that this shall not be allowable if it occurs in consecutive samples or in more than

(*a*) Twenty (20) per cent of the standard samples when five (5) or more samples have been examined per month.
(*b*) One (1) standard sample when less than five (5) samples have been examined per month.

Provided further that when all five of the standard one hundred milliliter (100 ml.) portions constituting a single standard sample show the presence of organisms of the coliform group, daily samples from the same sampling point shall be collected promptly and examined until the results obtained from at least two consecutive samples show the water to be of satisfactory quality.[6]

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[5] When this occurs, and when waters of unknown quality are being examined, simultaneous tests should be made on multiple portions of a geometric series ranging from 10 ml. to 0.1 ml. or less.

3.25. The procedure given, using a standard sample composed of five standard portions, provides for an estimation of the most probable number of coliform bacteria present in the sample as set forth in the following tabulation:

Number of portions		Most probable number of coliform bacteria per 100 ml.	
Negative	Positive	When 5-10 ml. portions are examined	When 5-100 ml. portions are examined
5	0	Less than 2.2	Less than 0.22
4	1	2.2	.22
3	2	5.1	.51
2	3	9.2	.92
1	4	16.0	1.60
0	5	More than 16.0	More than 1.60

4. As to the Physical and Chemical Characteristics

4.1. *Physical characteristics.*—The turbidity of the water shall not exceed 10 p.p.m. (silica scale), nor shall the color exceed 20 (standard cobalt scale). The water shall have no objectionable taste or odor.

4.2. *Chemical characteristics.*—The water shall not contain an excessive amount of soluble mineral substance, nor excessive amounts of any chemicals employed in treatment. Under ordinary circumstances, the analytical evidence that the water satisfies the physical and chemical standards given in sections 4.1 and 4.21 and simple evidence that it is acceptable for taste and odor will be sufficient for certification with respect to physical and chemical characteristics.

4.21. The presence of lead (Pb) in excess of 0.1 p.p.m., of fluoride in excess of 1.0 p.p.m., of arsenic in excess of 0.05

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[6] When this occurs, and when waters of unknown quality are being examined, simultaneous tests should be made on multiple portions of a geometric series ranging from 100 ml. to 1.0 ml. or less.

p.p.m., of selenium in excess of 0.05 p.p.m., shall constitute ground for rejection of the supply.

These limits are given in parts per million by weight and a reference to the method of analysis recommended for each determination is given in section 4.31. Salts of barium, hexavalent chromium, heavy metal glucosides, or other substances with deleterious physiological effects shall not be allowed in the water supply system.

Ordinarily analysis for these substances need be made only semi-annually. If, however, there is some presumption of unfitness because of these elements periodic determination for the element in question should be made more frequently.

4.22. The following chemical substances which may be present in natural or treated waters should preferably not occur in excess of the following concentrations where other more suitable supplies are available in the judgment of the certifying authority. Recommended methods of analysis are given in section 4.3.

Copper (Cu) should not exceed 3.0 p.p.m.

Iron (Fe) and manganese (Mn) together should not exceed 0.3 p.p.m.

Magnesium (Mg) should not exceed 125 p.p.m.

Zinc (Zn) should not exceed 15 p.p.m.

Chloride (Cl) should not exceed 250 p.p.m.

Sulfate (SO_4) should not exceed 250 p.p.m.

Phenolic compounds should not exceed 0.001 p.p.m. in terms of phenol.

Total solids should not exceed 500 p.p.m. for a water of good chemical quality. However, if such water is not available, a total solids content of 1,000 p.p.m. may be permitted.

For waters softened by the lime soda process the total alkalinity produced should not exceed the hardness by more than 35 p.p.m. (calculated as $CaCO_3$).

For chemically treated waters the phenolphthalein alkalinity (calculated as $CaCO_3$) should not be greater than 15 p.p.m. plus 0.4 times the total alkalinity. This requirement limits the permissible pH to about 10.6 at 25° C.

For chemically treated waters the normal carbonate alkalinity should not exceed 120 p.p.m. Since the normal alkalinity is a function of the hydrogen ion concentration and the total alkalinity, this requirement may be met by keeping the total alkalinity within the limits suggested when the pH of the water is within the range given. These values apply to water at 25° C.

pH range	*Limit for total alkalinity (p.p.m. as $CaCO_3$)*
8.0 to 9.6	400
9.7	340
9.8	300
9.9	260
10.0	230
10.1	210
10.2	190
10.3	180
10.4	170
10.5 to 10.6	160

0.3. Recommended methods of analysis:

4.31. Ions with required limits of concentration.

Arsenic (As): Official and Tentative Methods of Analysis. Association of Official Agricultural Chemists, 1940, p. 390; also "Colorimetric Microdetermination of Arsenic," Morris B. Jacobs and Jack Nagler. Industrial and Engineering Chemistry, Anal. Ed., 14:442 (1942).

Fluoride (F): Standard Methods for the Examination of Water and Sewage. American Public Health Association, 1936, p. 36; also Methods of Determining Fluorides, Committee Report, A. P. Black, Chairman. Journal American Water Works Association, 33:1965-2017 (1941).

Lead (Pb): Standard Methods for the Examination of Water and Sewage. American Public Health Association, 1936, p. 26.

Selenium (Se): Official and Tentative Methods of Analysis. Association of Official Agricultural Chemists, 1940, pp. 11 and 417; also Robinson, W. O., Dudley, H. C., Williams, K. T., and Byers, Horace, G.: The Determination of Selenium and Arsenic by Distillation. Industrial and Engineering Chemistry, Anal. Ed., 6:274 (1934).

4.32. Ions and substances with suggested limits of concentration.

Copper (Cu): Standard Methods for the Examination of Water and Sewage. American Public Health Association, 1936, p. 25.

Iron (Fe) and manganese (Mn); Ibid, p. 74 and p. 82.[7]

Magnesium (Mg): Ibid, p. 79.[7]

Zinc (Zn): Ibid, p. 28.[7]

Chloride (Cl): Ibid, p. 34.[7]

Sulfate (SO_4): Ibid, p. 85.[7]

Phenolic compounds: Ibid, p. 245.[7]

With dibromquinonechlorimide as an indicator.

Total solids: Ibid, p. 56.[7]

Alkalinity: Ibid, pp. 59 and 64.[7]

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[7] For the chemical determinations referred to in this report, when given, the methods of analysis recommended by the Association of Official Agricultural Chemists are satisfactory and may be substituted for those recommended by the American Public Health Association, which are specifically cited.

MANUAL OF RECOMMENDED WATER SANITATION PRACTICE

(PREPARED BY TECHNICAL SUBCOMMITTEE)

This manual is not to be considered as part of the Standards which must be met in order to obtain certification of the water supply, but is intended to serve as a guide to the reporting agency.

INTRODUCTION

In its report accompanying the 1942 Drinking Water Standards the Advisory Committee recommended, as the principal change to be incorporated in the revision, a separation of the text into (*a*) that portion containing the statement of the Standards, and (*b*) that portion which constitutes a recommended manual of water works practice, representing the judgment of the technical subcommittee, composed of officers of the Public Health Service, and which is to serve as a guide to the reporting agency. The Advisory Committee further stated, "This latter portion of the text is not to be considered as part of the Standards which must be met in order to obtain certification of the water supply."

In undertaking the preparation of a manual such as envisioned by the Advisory Committee, the technical subcommittee has recognized that no comprehensive treatise on water supply practice is needed in this connection, in view of the several excellent texts which have been published on this subject, including a recent manual (1) issued by the American Water Works Association. It considers its task, in fact, to be limited to a comparatively brief and general description of those features of water supply systems and their operation which may be said to conform to accepted principles of good sanitation. It is very largely with these features that the reporting agency is concerned in forming a judgment as to whether or not a particular water supply may meet reasonably acceptable sanitary requirements in respect to its source and protection, as prescribed in section 2 of the Standards.

As a further aid to the reporting agency, a section designated as part IV, containing an explanatory discussion of the bacteriological and chemical requirements of the Standards, has been added to this manual. This section is virtually an appendix, as it deals with a subject quite distinct from that of the other sections of the manual.

The main text of the manual, other than part IV, is divided into three sections, parts I, II, and III. In part I are given in outline form those features of water supply systems which may be included in the sanitary survey, including a list of major sanitary defects and health hazards which would be detrimental to the safety of a water supply. In parts II and III are two sections dealing, respectively, with recommended sanitary requirements for water treatment and for water distribution systems. These two parts of the manual are in the form of a connected discussion, amplifying the outline material given in part I.

In preparing the manual, full advantage has been taken of criticisms of the preliminary text by various members of the Advisory Committee. Although it obviously would be impossible to reconcile fully the conflicting views of any group as large as this committee, an effort has been made to follow, so far as practicable, the concensus of opinion among a majority of the committee. The writers of the manual take this opportunity to acknowledge gratefully the many helpful comments which have been furnished by members of the Advisory Committee on the material herein presented.

In preparing the present manual, cognizance has been taken of the need which exists for affording somewhat greater sanitary protection to certain features of public water supply systems and their operation under the existing wartime conditions than might be considered as essential under those of peace. In general, however, an effort has been made to write the manual from the viewpoint of normal requirements for water sanitation as they would be considered by the reporting agency in connection with the application of the Drinking Water Standards.

PART I

PHYSICAL FEATURES OF WATER SUPPLY SYSTEMS AND THEIR SANITARY PROTECTION

The physical features of water supply systems may be said to include all of those parts which come within the definition given in paragraph 1.6 of the Standards. According to this definition, "a water supply system includes the works and auxiliaries for collection, treatment, and distribution of the water from the source of supply to the free-flowing outlet of the ultimate consumer." Strictly interpreted, sanitary protection would be concerned with all of those parts of a water system which come within this definition, though for practical purposes the attention may be concentrated mainly on those parts which have to do with sources, treatment, and distribution of the water.

(a) Scope of Requisite Information as to Source and Protection

In order that the administrative authorities may have the necessary information upon which to base their action, it is required that each water supply coming under consideration should be carefully studied with reference to its source and protection. The precise scope of such a study and of the report thereon will vary according to the circumstances existing in each individual case and cannot be fully specified in any general terms. The general procedure, however, should be substantially as follows:

1. *A sanitary survey of the water supply should be made by a competent person.* The reliability of the data collected will depend largely upon the competence of the person by whom the survey is made, and the careful selection of personnel for this duty is of primary importance. The qualifications which constitute "competence" cannot be precisely defined, but, in general, the person making the survey should have received a technical education in the basic sanitary sciences equivalent to that given in a course in sanitary engineering in a recognized college of engineering or school of public health; he should have a broad knowledge of the sanitary features and physical facts concerning water supplies for potable use, and he should understand the essential features of water purification plants, their operation and methods of testing.

2. *A brief general description of the water supply should be submitted.* This should include the name of the owner of the supply and a brief description of sources and catchment areas, of the storage available both prior to and following any treatment, and of the plant, with date of installation of main works, and record of subsequent extensions or alterations.

3. *A brief summary of the pertinent facts relating to the sanitary condition of the water supply, as revealed by the field survey, should be submitted.* The following outline will serve to indicate the general scope of the survey. Not all of the items, however, would be pertinent to any one supply, and in some cases items not in the list would be important. Reference should be made to parts II and III of this manual for certain detailed recommendations bearing on various parts of this outline.

(a) Small Ground Water Supplies

1. Nature of soil and underlying porous strata, whether of clay, sand, or gravel; thickness of water-bearing strata; depth to water table.
2. Nature of rock penetrated, noting especially existence of porous limestone.
3. Depth to strainers; length of strainer; depth of casing; well construction—material—diameter.
4. Slope of water table, preferably as determined from observational wells, or as indicated presumptively but not certainly by slope of ground surface.
5. Nature, distance, and direction of sources of pollution.
6. Possibility of surface drainage water entering the supply, and of wells being flooded by nearby streams.
7. Methods of protection.
8. Pump house construction (floors, drains, etc.); capacity of pumps; drawn-down when pumps are in operation.
9. Disinfection: equipment; supervision; laboratory control.

(b) Large Ground Water Supplies

1. General character of local geology.
2. Extent of drainage area likely to contribute water to the supply.

3. Size and topography of catchment area; slope of ground surface.

4. Nature and porosity of soil and underlying strata, whether clay, sand, gravel, rock (especially limestone); coarseness of sand or gravel; thickness of water-bearing strata.

5. Depth to strainers; length of strainer; depth of casing.

6. Population on the drainage area.

7. Nature, distance, and direction of local sources of pollution.

8. Pump house construction (floors, drains, etc.); capacity of pumps; draw-down when pumps are in operation.

9. Possibility of surface drainage water entering the supply; methods of protection.

10. Methods used for protecting the supply against pollution, by means of sewage treatment, waste disposal, and the like.

11. Protection of collecting well at top and on sides; protection other than check valve or gate against backflow of drain, etc.

12. Availability of an impure emergency supply.

13. Use of tile pipes or other conduits not tight where ground water may be contaminated.

14. Disinfection: equipment; supervision; laboratory control.

Examples of sanitary defects in ground water supplies are:

(1) Caves, sink holes, or abandoned borings used for surface drainage or sewage disposal in vicinity of the source; fissures or open faults in strata overlying water-bearing formations.

(2) Casing of tubular wells leaky, or not extended to sufficient depth, or not extended above ground or floor of pump room, or not closed at top; or casing improperly used as a suction pipe.

(3) Collecting well or reservoir subject to backflow of polluted water through improper drain.

(4) Source of supply or structures subject to flooding.

(5) Leak in systems under vacuum.

(6) Air lift line or lines cross-connected to a sewer or secondary water supply.

(c) Surface Water Supplies, Unfiltered

1. Nature of surface geology; character of soil and rocks.

2. Character of vegetation, forests, cultivated land, etc.

3. Population and sewered population per square mile of catchment area.

4. Methods of sewage disposal, whether by diversion from watershed or by treatment.

5. Character and efficiency of sewage treatment works on watershed.

6. Proximity of sources of fecal pollution to intake of water supply.

7. Proximity, sources, and character of industrial wastes.

8. Adequacy of supply as to quantity.

9. For lake or reservoir supplies: wind direction and velocity data; drift of pollution; sunshine data (algae).

10. Character and quality of raw water—algae, turbidity, color, coliform (M. P. N.), (average, minimum and maximum).

11. Nominal period of detention in reservoir or storage basin.

12. Probable minimum time required for water to flow from sources of pollution to reservoir and through reservoir to intake.

13. Shape of reservoir, with reference to possible currents of water, induced by wind, from inlet to water supply intake.

14. Measures taken to prevent fishing, boating, landing of airplanes, swimming, wading, ice cutting, permitting animals in or upon the water, etc.

15. Efficiency and constancy of policing.

16. Disinfection of water: Kind and adequacy of equipment, duplication of parts; effectiveness of treatment, adequacy of supervision and laboratory control; contact period after disinfection; whether residual free chlorine or chloramines in chlorinated water; residuals carried.

Examples of sanitary defects are:

(1) Absence or inadequacy of chlorination, or lack of proper control of chlorination; insufficient contact period with chloramines present in treated water.

(2) Insufficient restrictions on recreational use of streams and reservoirs, together with their marginal lands, in the local catchment area.

(3) Existence of sources of pollution, such as population on watershed lumbering, hunting, and other activities; leaching cesspools, or sewers draining into streams or lakes of the catchment area, or into the marginal lands adjacent to them.

(4) Improper location of intake with respect to bottom of reservoir and current, or to surface drainage water inlets.

(5) Intake exposed and accessible to trespassers.

(6) For lake supplies: Vessels passing near intakes; drift of ice fields; dumping of dredging, garbage, etc., into lake near intakes; inadequate toilet facilities on cribs; nonexamination of employees as carriers of water-borne diseases.

(d) Surface Water Supplies, Filtered

1. Catchment area: Size, topography; population density (sewered and unsewered); surface geology; reservoirs (capacity and location).

2. Sources of pollution: Nature; distance from intake (miles and time of travel); amounts and distances of sewered population.

3. Sewage treatment on watershed: Extent; methods; populations served; effectiveness and uniformity of results.

4. Raw water characteristics: Turbidity, color, alkalinity, hardness, iron, etc.; bacterial quality (average and ranges); variations in quality, especially after heavy rainfall or at times of high run-off.

5. Rated capacity of filter plant (mgd.): Output (average and maximum daily); maximum capacity of pumps.

6. Coagulant system: Type (solution or dry feeding); chemicals used; dosage rates (average, maximum, and minimum); number and capacity of units; reserve units.

7. Mixing and flocculation basins: Type; flash mixing (average and minimum times); flocculation (average and minimum times); number, size, and arrangement of units; provisions for cleaning.

8. Sedimentation basins (number, size, and retention capacity): Plain sedimentation; post-coagulation sedimentation; methods of cleaning; flexibility of operation; efficiency of turbidity and bacterial removal.

9. Filters: Type (pressure or gravity); number; sizes and rated

capacities (net filtering area); effective size and uniformity coefficient of sand; washing system (direct or from storage, rates of wash water application); loss-of-head gages; rate controllers (average and maximum rates of filtration).

10. Filtered water storage: Capacity; location; arrangement; covered or uncovered; protection against contamination; methods of cleaning; added storage in distribution system.

11. Aeration: Kind, purpose, capacity, location in purification system; efficiency.

12. Disinfection: Kind, stages (if more than one); location in purification system; capacity; method of operation; operation control; average, maximum and minimum dosage; chlorine—ammonia ratios (if ammonia used); simple or "break-point" chlorination (if used); efficiency of each stage.

13. Plant operation and control: Technical supervision (trained or untrained, full-time or part-time); number of operators; laboratory control (kind and frequency of tests); plant and laboratory records (kind, extent, use, etc.); meteorological records.

Examples of sanitary defects are:

(1) Excessive raw water pollution in relation to extent of treatment provided [see part II, A, (1)]; existence of nearby uncontrolled sources of raw water pollution.

(2) By-pass connections for raw water or partially treated water, whereby insufficiently purified water may be discharged into the distribution system.

(3) Existence of cross-connections within the plant, between conduits or basins carrying untreated or partly treated water and those containing completely treated water.

(4) Deficient output capacity of treatment works, necessitating excessive overloading or occasional by-passing of units.

(5) Lack of competent supervision and operation, or of adequate laboratory control.

(6) Deficient or inaccurate operation or laboratory records.

(7) Lack of suitable devices for measuring and recording volumes of water treated; for maintaining continuity of coagulant and

(3) Existence of sources of pollution, such as population on watershed lumbering, hunting, and other activities; leaching cesspools, or sewers draining into streams or lakes of the catchment area, or into the marginal lands adjacent to them.

(4) Improper location of intake with respect to bottom of reservoir and current, or to surface drainage water inlets.

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(d) Surface Water Supplies, Filtered

1. Catchment area: Size, topography; population density (sewered and unsewered); surface geology; reservoirs (capacity and location).

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3. Sewage treatment on watershed: Extent; methods; populations served; effectiveness and uniformity of results.

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5. Rated capacity of filter plant (mgd.): Output (average and maximum daily); maximum capacity of pumps.

6. Coagulant system: Type (solution or dry feeding); chemicals used; dosage rates (average, maximum, and minimum); number and capacity of units; reserve units.

7. Mixing and flocculation basins: Type; flash mixing (average and minimum times); flocculation (average and minimum times); number, size, and arrangement of units; provisions for cleaning.

8. Sedimentation basins (number, size, and retention capacity): Plain sedimentation; post-coagulation sedimentation; methods of cleaning; flexibility of operation; efficiency of turbidity and bacterial removal.

9. Filters: Type (pressure or gravity); number; sizes and rated

capacities (net filtering area); effective size and uniformity coefficient of sand; washing system (direct or from storage, rates of wash water application); loss-of-head gages; rate controllers (average and maximum rates of filtration).

10. Filtered water storage: Capacity; location; arrangement; covered or uncovered; protection against contamination; methods of cleaning; added storage in distribution system.

11. Aeration: Kind, purpose, capacity, location in purification system; efficiency.

12. Disinfection: Kind, stages (if more than one); location in purification system; capacity; method of operation; operation control; average, maximum and minimum dosage; chlorine—ammonia ratios (if ammonia used); simple or "break-point" chlorination (if used); efficiency of each stage.

13. Plant operation and control: Technical supervision (trained or untrained, full-time or part-time); number of operators; laboratory control (kind and frequency of tests); plant and laboratory records (kind, extent, use, etc.); meteorological records.

Examples of sanitary defects are:

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(3) Existence of cross-connections within the plant, between conduits or basins carrying untreated or partly treated water and those containing completely treated water.

(4) Deficient output capacity of treatment works, necessitating excessive overloading or occasional by-passing of units.

(5) Lack of competent supervision and operation, or of adequate laboratory control.

(6) Deficient or inaccurate operation or laboratory records.

(7) Lack of suitable devices for measuring and recording volumes of water treated; for maintaining continuity of coagulant and

chlorine dosage; deficient retention periods in settling basins; or inadequate areas, depths, sizes of sand or washing facilities for filters.

(8) Lack or deficiency in proper chlorination equipment and control, or failure to maintain proper chlorine residuals in the treated effluent at all times.

(9) Lack of suitable protection for purified water; storage capacity less than requirements for safety.

(e) Pumping Station and Collecting System

1. Number, type, and capacity of pumps, including reserve; condition of equipment and method of operation; condition of suction pipes.
2. Emergency intakes.
3. Emergency supply of power; record of power shut-down; effect of shut-down on surges through conduits, etc.
4. Recording apparatus on suction well elevation; rise and fall of suction well elevation.
5. Screens for fish and debris.
6. All sewers cast iron, or otherwise.
7. Curb walls around wells to protect against surface drainage.
8. Continuous or intermittent operation.

Examples of sanitary defects are:

(1) Leaky suction pipes.

(2) Pump not self-priming; unsafe water used for priming.

(3) Suction well or suction pipes unprotected from surface or sub-surface pollution.

(4) Suction well subject to pollution through backflow of polluted water through drain.

(5) Improper location or inadequate protection with reference to flood waters.

(6) Lack of suitable provision for insuring continuity of pumping service under all possible conditions.

(f) Distribution System

1. Area and population supplied (proportion to total within corporate limits).

2. Type of distribution system; whether by gravity, direct pumping, indirect pumping, etc.

3. Use, location, and capacity of reservoirs and standpipes.

4. Adequacy of distribution system with respect to area served, sizes of mains and laterals, circulation of water, storage provided, etc.

Examples of sanitary defects are:

(1) Existence of cross-connections between primary supply and secondary supply of questionable safety at any point in the distribution system.

(2) Return to the system of any water used for cooling; hydraulic operations, etc.

(3) Absence, or inadequate protection, or improper location of distribution reservoirs, standpipes, or elevated pressure tanks.

(4) Intermittent service, resulting in reduced or negative pressures in distribution system; sizes of mains and laterals inadequate for preventing negative pressures; presence of dead ends permitting reduced or negative pressures.

(5) Connections to sprinkler systems using toxic solutions as antifreeze.

(6) Repumping on consumer premises when pressure is low (causing negative head).

(7) Connection to sewers and sewer-flushing chambers, and improperly located blow-offs in distribution system.

(8) Lack of check valves on consumer services to prevent backflow (especially from high building storage tanks), or from ammonia systems at ice plants, or from hot water systems.

(9) Existence of hydrant wash lines connected to sewer.

(10) Presence of a secondary water system on premises where public system exists.

(11) Lack of suitable plumbing ordinances prohibiting the use of backflowing toilet or sink fixtures, or permitting the use of storage tanks connected directly to sanitary fixtures without proper vacuum breaker inlets, or permitting unsafe cross-connections between potable and nonpotable water supplies in private premises.

(12) New connections of pipe joined to the system without prior disinfection of pipes.

(13) Existence of tile or other leaky pipes in distribution system.

(14) Improper location of water pipes in relation to sewers and storm water drains.

PART II

RECOMMENDED SANITARY REQUIREMENTS FOR WATER TREATMENT SYSTEMS

A. GENERAL REQUIREMENTS

(1) *Extent of Treatment*

(*a*) For purposes of classification with respect to treatment requirements, waters acceptable for treatment may be divided into the following groups:

GROUP 1. *Waters requiring no treatment.*—This group would be limited to underground waters subject to no possibility of contamination and meeting in all respects the requirements of these Standards. as shown by regular and frequent sanitary inspections and laboratory tests.

GROUP 2. *Waters requiring simple chlorination, or its equivalent.* —This group would include both underground and surface waters, subject to a low degree of contamination and meeting the requirements of these Standards in all respects except as to coliform bacterial content, which should average not more than 50 per 100 ml. in any month.

GROUP 3. *Waters requiring complete rapid-sand filtration treatment, or its equivalent, together with continuous postchlorination.*—This group would include all waters requiring filtration treatment for turbidity and color removal, waters of high or variable chlorine demand, and waters polluted by sewage to an extent such as to be inadmissible to groups 1 and 2, but containing numbers of coliform bacteria averaging not more than 5,000 per 100 ml. in any month and exceeding this number in not more than twenty (20) per cent of the samples examined in any month.

GROUP 4. *Waters requiring auxiliary treatment in addition to complete filtration treatment and postchlorination.*—This group would include waters meeting the requirements of group 3 with respect to limiting monthly average coliform numbers, but showing numbers exceeding 5,000 per 100 ml. in more than twenty (20) per cent of the samples examined during any month and not exceeding 20,000 per 100 ml. in more than five (5) per cent of the samples examined during any month.

Note.—By "auxiliary treatment" is meant presedimentation or prechlorination, or their equivalent, either separately or combined, as may be necessary. Long-time storage, for periods of 30 days or more, represents a permanent and reliable safeguard which in many cases would provide something more than an effective substitute for one or both of the two other methods indicated.

Remarks.—(*a*) Although group 1 conceivably might include exceptional surface waters free of any possible contamination and further protected by storage, it hardly can be considered as a safe general rule to admit any surface water to a public supply without chlorination as a minimum safeguarding treatment, in view of the present increased hazards of chance contamination resulting from the extension of recreational and migratory travel to many hitherto inaccessible places. Under wartime conditions, additional need would exist for extreme precaution in this respect.

(*b*) The limiting monthly average coliform numbers stated for waters of groups 2 and 3 are intended as guides rather than inflexible rules, though they are based on extensive observational data (2) fairly representing present water treatment practice in this country. Certain recent improvements in water chlorination and its control offer promise of increasing the margin of safety of water purification efficiency, with respect to bacterial removal. These improvements have not, however, become fully incorporated into general practice throughout the country, nor does it appear desirable that they should be regarded as warranting any relaxation in the requirements for raw water quality which experience and present standards of safety would indicate as being necessary for providing adequate protection to sources of water supply in general.

(*c*) For waters of group 4, which differ from those of group 3 only in respect to variability, auxiliary treatment is intended mainly as a factor of safety in controlling variations in coliform numbers within the range of 5,000 to 20,000 per 100 ml. The larger of these two figures represents the maximum safe limit for prechlorination, or its equivalent, in addition to filtration treatment and postchlorination.

(*d*) Waters failing to meet the requirements of groups 1, 2, 3, or 4 would be considered as unsuitable for use as a source of water supply, unless they could be brought into conformance with these requirements by means of prolonged preliminary storage, or some other measure of equal permanence and reliability.

(2) *Other Raw Water Requirements*

In addition to meeting the aforesaid bacterial requirements, waters acceptable for treatment should not contain any toxic or otherwise harmful substances, or organisms not readily and completely removable by ordinary water treatment. Raw waters should be free of excessive amounts of acid, microscopic organisms, or organic matters causing any interference with the normal operation and efficiency of water treatment processes.

B. DESIGN AND CONSTRUCTION

In general, the design and construction of individual water treatment plants will vary with local circumstances and should be in accordance with the results of experiments on the water to be treated. The following recommendations, therefore, are intended only as a general guide to good practice and are to be interpreted somewhat broadly in the light of the particular raw water characteristics and other conditions which may be involved in a given situation.

(1) *Plant Delivery Capacity*

The delivery capacity of a treatment plant, including filtered water storage at the plant, should always be in excess of the maximum expected draft on any day of the year. The excess of provided capacity over average daily draft may vary from 50 to 100 per cent and normally should be at least 50 per cent.

(2) *Plant Location*

The treatment plant, including raw water and effluent pumps, should be located at an elevation sufficiently high above surrounding bodies of water and have sufficient auxiliary power to insure continuance of operation under all circumstances, including floods. If located in a valley, the site should be adequately drained so that no surface water can gain access to wells, basins, filter tanks or other units. The plant should be located so that no conduit, basin, or other structure containing or conducting water in the process of treatment can possibly be affected by leakage from any sewer, drain, or other source of contamination.

(3) *Presettling Reservoirs*

Presettling reservoirs should be located above the influence of flood waters. They should be at least two in number, so as to permit continuous operation under all circumstances, and should be of sufficient capacity to afford a nominal retention period of at least 1 day and preferably 2 or 3 days. Provision should be made for rapid and convenient removal of sludge from the reservoirs. In the treatment of highly polluted waters of variable quality, provision should be made for coagulation at the inlet and for prechlorination at the inlet or the outlet of the reservoirs, whenever such measures may be necessary. Reservoirs should be provided with boats and life preservers for the protection of employees.

(4) *Coagulation-Sedimentation Basins*

In order to insure continuous operation, basins for flocculation and sedimentation of coagulated waters should be at least two in number, should be designed for series or parallel operation, and preferably should provide a total retention period of at least 5 or 6 hours, except where the use of preliminary mixing and flocculating devices and continuous sludge removal permit somewhat lower periods with unimpaired efficiency. Inlets and outlets of ordinary straight-flow basins should be at opposite ends of the basins and, if necessary, should be provided with baffles so located as to prevent short circuiting. Similar baffles may be advantageously installed in the settling compartment. The maximum velocity of flow in the settling compartment should not exceed that which usually is provided in well-designed basins of this type. The length of settling compartments in such basins, if rectangular, should be preferably at least twice the width. Stilling compartments should be provided at basin inlets. cated well downstream from the intake, or intakes, at points removed If stream use will permit, sludge drains may discharge at points lofrom the influence of cross-currents passing the intake. Otherwise, suitable sludge disposal areas should be provided. The depth of basins should be such as to maintain proper velocity of flow and sludge removal, the permissible depth being slightly lower with continuous sludge removal. Flow line elevations should not vary more than a few inches above or below the normal level.

Flash mixing and flocculation tanks.—Preliminary flash mixing and flocculating equipment, capable of adequate flexibility of adjustment to provide optimum flocculation under varying raw water conditions, is a highly desirable feature of well-designed modern filtration plants and should be credited as a distinct addition to the sanitary protection afforded by a purification system. An ideal combination of flash mixing and flocculation would provide about 1 to 2 minutes of violent agitation followed by about 20 to 30 minutes of slow mixing to promote flocculation.

(5) *Coagulant System*

Rapid-sand filtration plants should be provided with efficient modern devices for measuring and adding coagulants to the water under treatment. All chemical dosing equipment, whether of the dry-feed or solution-feed type, should have at least one unit in reserve throughout and should be provided with effective recording and alarm devices to insure continuity of service at all times. An accurate flow meter should be provided for the water treated and also for dry-feed equipment, suitable gravimetric devices for measuring the amount of chemicals added from hour to hour. All chemical feed equipment should be capable of ready adjustment to variations in the flow of water being treated.

(6) *Filters*

Slow-sand.—Slow-sand filters, if properly designed and operated, are applicable to the treatment of certain types of relatively clear waters. They preferably should be covered, should be provided with loss-of-head gages, should have a sand depth of 36 to 40 inches, and should never be operated with less than 20 inches of depth. The sand should have an effective size of 0.25 to 0.35 mm. and should be operated at rates of about 2.5 million gallons per acre daily. In operating slow-sand filters, care should be taken to avoid any sudden increases in the rate or filtration.

Rapid-sand.—Rapid-sand filters should be preferably of the gravity type, in order to permit ready and continuous inspection. The depth, effective size, and uniformity of sand should be in accordance with the requirements of adequate yield and filter efficiency. Ordinarily, sand depths of about 30 inches are customary, with effective sand size ranging from 0.40 to 0.50 mm. and uniformity coefficient from 1.5 to 2.0. The rate of filtration should conform to established practice, preferably not exceeding 3 gallons per minute per square foot of filtering area.

In general, rapid-sand filters should be designed and operated with a view to maintaining reasonably high efficiency of bacterial removal, and the filtering medium should be in good condition, free of mud balls, cracks, and other hindrances to efficient filtration. Efficient loss-of-head gages, rate controllers, and other essential control devices should be provided.

(7) *Filtered Water Storage Reservoirs*

Filtered water reservoirs at the plant preferably should be covered and located near to, but physically separated from, the plant. Where located below filters, adequate protection against leakage of drainage water from other parts of the plant into the reservoirs should be provided. Trap doors and inspection openings, should be properly sealed and locked. Suitable vents, protected against outside contamination, should be provided. All effluent pipes should be properly sealed against leakage and tested by frequent inspections. Filtered water reservoirs should be thoroughly tight against external leakage, should be situated above the ground water table, and preferably should have no walls in common with any other plant units containing water in the process of treatment.

(8) *Interconnections, Cross-Connections, Open Connections, and Partition Walls*

(*a*) No cross-connection or interconnection should be permitted to exist in a filtration plant between any conduit carrying filtered or postchlorinated water and another conduit carrying raw water or water in any prior stage of treatment.

(*b*) No conduit or basin containing finished water should be permitted to have a common division wall with another conduit or basin containing raw water or water in any prior stage of treatment.

(*c*) Rewash or filter-to-waste conduits should not be directly connected to any drainage conduit, but should be protected by a suitable one-way gap-delivery connection, so that no back-siphonage can occur under any condition.

(*d*) No conduit carrying raw water or any water in a prior stage of treatment should be located directly above another conduit carrying finished water, with a single common partition between them. This rule is not strictly applicable, however, to cast-iron pipes with tight joints carried in the open and readily accessible for inspection and repair.

(9) *Drains*

All drainage conduits should be constructed so as to be thoroughly tight against external leakage. They should discharge at points in a river or lake so located that no currents of water can under any circumstances be carried from a drain outlet to the plant intake, or to any other water intake located in the vicinity of the plant. No domestic or other sewer should be permitted to be discharged into the river or lake in the vicinity of a treatment plant intake, or directly above such intake, nor should any drain carrying contaminated surface water be permitted to be discharged likewise.

(10) *Chlorination*

(*a*) *General.*

Chlorination equipment should be selected, installed, and operated so that continuous and effective disinfection is secured under the required local conditions.

(*b*) *Chlorination equipment.*

1. Chlorination equipment should have a maximum capacity at least 50 per cent greater than the highest expected dosage to be applied at any time. It should be capable of satisfactory operation under every prevailing hydraulic condition at the plant.

2. Automatic proportioning of the chlorine dosage to the rate of flow of the water treated should be provided at the larger plants and at all plants where the rate of flow varies more than 50 per cent above or below the average flow. Manual control should be permissible only where the rate of flow is relatively constant and an attendant is always at hand to effect promptly the necessary adjustments in dosage.

3. All clorination equipment should be installed in duplicate, so as to provide stand-by units for insuring uninterrupted operation. Duplicate units should be operated frequently to insure workability. A complete stock of spare parts and tools should be maintained for emergency replacements or repairs.

4. A reliable and uninterrupted supply of water, free of coarse suspended matter, should be available under adequate pressure to insure the continuous operation of solution-feed chlorinators. Hydraulically or electrically driven pumping equipment, if used for maintaining such pressure, should be provided with alternative sources of power where necessary to insure continuous operation.

5. Scales, preferably of the indicating and recording type, should be provided for weighing the cylinders of chlorine and checking the losses in weight of chlorine as fed from the cylinders during successive intervals of time. These scales should be sufficiently accurate and sensitive to measure such losses with suitable precision.

6. A sufficient number of cylinders of chlorine should be connected to the chlorinator in use so that adequate operating pressures will be maintained at various temperatures.

(*c*) *Hypochlorite solutions.*

1. Solutions of calcium or sodium hypochlorite should be prepared in a separate mixing tank, then diluted and allowed to settle, so that only a clear supernatant liquid is withdrawn to the solution storage tank and to the chlorinator.

2. The strength of stored calcium hypochlorite solutions should be checked frequently by laboratory test in order to ascertain that no loss of strength has occurred. Calcium hypochlorite solutions should be prepared freshly every 4 or 5 days, unless properly alkalinized with sodium carbonate.

(*d*) *Safety requirements.*

1. Suitable gas masks and a small bottle of ammonia for testing for leaks should be kept at convenient points immediately outside the room or enclosures in which chlorine is being stored or is in use. Gas masks should be inspected at regular intervals and kept in serviceable condition.

2. Chlorinating equipment and cylinders of chlorine should be housed preferably in separate buildings above the ground level, as a measure of safety.

3. The room or building housing chlorinators in service should be maintained at a temperature of above 60° F., but never in excess of the normal summer temperature. The cylinders of chlorine should be shielded, where necessary, from excessive heat or cold. Direct heat should not be applied to cylinders of chlorine, nor should hot water be poured over them or come in contact with the cylinder valve.

4. Adequate ventilation should be provided for all enclosures in which chlorine is being fed or stored.

5. All joints of tubing connecting chlorine cylinders and chlorinators should be kept absolutely tight and inspected frequently to insure tightness. Tubing should slope upward from the cylinders.

(*e*) *Control of chlorination.*

1. Chlorine should be applied continuously to the filtered effluent at a point where thorough and rapid mixing with the treated water will be effected. Free active chlorine should be in contact with the treated water for not less than 20 minutes, or chloramine preferably for at least 3 hours, before the treated water reaches the first consumer.

2. The proper dosage of chlorine will be determined by regular and frequent routine bacteriological and residual chlorine tests, both at the plant and at various points in the distribution system. In

general, a safe desirable minimum of residual free chlorine at distant points in the distribution system would be 0.05 or 0.10 p.p.m., depending on circumstances. For chloramines, the desirable residual would be somewhat higher. The residual carried in the finished water as delivered from the treatment plant should be regulated accordingly. At times of threatened or prevalent outbreaks of water-borne disease, the residual chlorine should be increased preferably to a minimum of 0.2 or 0.3 p.p.m. in all parts of the distribution system, if possible, regardless of tastes or odors in the delivered water. Similar measures should be taken in the event of any lapse in the normal efficiency of the treatment plant.

3. Routine sampling points should be maintained at the treatment plant and at several vital points in the water distribution system. Sample collections should be made regularly at the latter points and the samples tested bacteriologically and for residual chlorine. Chlorine demand tests should be made occasionally on samples collected in the distribution system for comparison with the results of similar tests at the treatment plant. Any abnormal increase in the chlorine demand, or decrease in the residual chlorine at any point in the distribution system, should be checked and, if consistently observed, followed up by a thorough physical investigation of that portion of the system.

4. The tests for residual chlorine should be made in accordance with the eighth edition of the "Standard Methods for the Examination of Water and Sewage, 1936" published jointly by the American Public Health Association and the American Water Works Association. This test should be made at least once during each successive period of 8 hours every day in the finished water at the treatment plant and at least three times weekly at regular sampling points in the distribution system.

5. Special care should be taken to maintain a detailed and accurate record of chlorination and the results thereof. Such a record should show: rate of flow of water treated, gross weight of chlorine cylinder in use, weight of chlorine used for 24 hours, setting of chlorinator, and time of making and results of residual chlorine test.

6. Unless bacteriological and other tests should indicate the need

of maintaining higher minimum concentrations of residual chlorine, at least 0.2 p.p.m. of free chlorine should be maintained in the treated water after a contact period of at least 10 minutes. When chloramine treatment is used for disinfection, the residual chlorine concentration, as indicated by the orthotolidine reagent, should be at least 0.4 p.p.m. after 2 hours of contact. Where "break-point" chlorination is practiced, a sufficient concentration of residual free chlorine should be maintained at the treatment plant so that it will be not less than 0.05 to 0.10 p.p.m. at all points in the distribution system. When required in specific instances, the minimum concentration of residual chlorine and the minimum retention period for the chlorinated water should be increased as directed by the State Department of Health.

7. Results of recent studies have indicated that the product of required concentration and period of contact of chloramine with water may range from 20 to 30 times the corresponding product for free active chlorine, in order to obtain comparable bactericidal action. The required dosage can be determined by means of "breakpoint" tests of the water and adjustment of the chlorine dosage so as to allow for some absorption of free chlorine in the distribution system initially. This absorption should diminish after the chlorine demand of organic matter remaining in the system has been satisfied.

C. OPERATION CONTROL

(1) *Supervision*

Every water treatment plant engaged in purifying water for domestic use should be under the charge of a technically trained supervisor. For plants treating variable or highly polluted raw waters, trained supervision should be continuous and full-time. For certain types of small plants, part-time trained supervision may be practicable under favorable circumstances. Under these conditions, the supervisor should be in constant touch with the plant attendants and available on call in any emergency, and should visit the plant at least twice each week.

(2) *Laboratory Tests and Control*

(*a*) The schedule of laboratory tests followed in controlling the operation of a water treatment plant will vary with the size of the plant and character of water treated, though certain minimum requirements may be stated. For the ordinary plant, the minimum schedule of laboratory tests should include determinations of air and water temperature, turbidity or color (or both), alkalinity, pH value, hardness, residual chlorine, bacterial count at 20° C. or 37° C. (or both), and coliform bacterial numbers, both presumptive and confirmed. Where "break-point" chlorination is practiced, a continuous record of free ammonia in the water to be chlorinated should be maintained. Occasionally special tests may be necessary, such as for residual alum, iron, manganese, or other undesirable constituents of the final effluent. Where prechlorination is used in addition to postchlorination, tests for residual chlorine should be made at each major stage of treatment and, in the raw water, tests for chlorine demand.

(*b*) For operation control at the plant, the frequency of tests, particularly for turbidity, residual chlorine, bacterial count, and coliform organisms, though dependent on the character of water treated and on its variability, should be such that at least one test each 24 hours and every day of the week will be carried out. For the larger plants, at least three sets of samples are usually collected daily for bacteriological tests. Determinations of turbidity and residual chlorine are made more frequently, sometimes at hourly intervals when the character of the raw or partly treated water is changing rapidly.[1]

(*c*) An important though somewhat less tangible element in judging the efficiency of plant operation is the general appearance of the plant and its surroundings. A neat, well-kept plant with attractive grounds is almost invariably an index of efficient operation, though, in some of the smaller plants especially, this criterion may not always be infallible. Mere neatness in the external maintenance of a plant, how-

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[1] The following rule, wholly arbitrary, would give sampling frequencies depending in part on the daily volume of water treated and on the density of raw water pollution.

$$N = \sqrt[3]{VC}$$

where N = number of samples per 24 hours,
V = volume of water treated in million gallons daily.
C = coliform number, M. P. N., in thousands per 100 ml.

According to this rule, the number of samples per 24 hours would range from 1 to 2 for a 1 mgd. plant with raw water coliforms 1 to 5 thousands per 100 ml. and from 5 to 8 for a 100 mgd. plant with the same range in coliform numbers.

ever, cannot offset lack of proper training on the part of the operator.

In rating the general efficiency of operation control, the following items are of primary importance:

(1) Training and experience of supervisor and operating staff.

(2) Adequacy of operation records.

(3) Efficiency of laboratory control.

(4) Suitability of plant design and construction to the character and pollution of the raw water.

(5) Capacity of the plant in relation to the average and maximum required output.

PART III

RECOMMENDED GENERAL SANITARY REQUIREMENTS FOR WATER DISTRIBUTION SYSTEMS

A. GENERAL

1. A water distribution system should be designed and constructed so as to provide at all times an adequate supply of water at ample pressure in all parts of the system.

2. The safety and palatability of the water should not be impaired in any manner while flowing through the distribution system, or any part thereof.

3. The system should be provided with sufficient valves and blowoffs so that necessary repairs can be made without undue interruption of service over any considerable area.

4. No unprotected open reservoir, or physical cross-connection whereby unsafe water can enter the distribution system, should be permitted.

5. The system should be tight against excessive leakage and its various mains and branches should be separated from rivers and other possible sources of contamination.

6. The system should be designed so as to afford effective circulation of water, with a minimum of dead ends.

7. The distribution system should be maintained in a sanitary manner, with due precautions against contamination of the water in any part of it as the result of necessary repairs, replacements, or extension of mains.

8. Frequent and regular bacteriological examinations should be made of water samples collected at various control points in the distribution system, with an immediate and thorough checking of any unusual results.

2. PIPING SYSTEM

1. The water mains should be of adequate size so that negative pressure will not occur under any condition of draft on the system.

2. Joints should be of such design and should be installed so as to show no leakage under a standard pressure test before covering. Materials used for caulking should be of a character such as not to foster the growth of coliform bacteria.

3. Corrective water treatment should be instituted where deposits in the mains tend to reduce the effective size and capacity of the pipes. For biological deposits, heavy chlorination may be effective.

4. The piping system should be designed so as to maintain an adequate positive pressure of water in all parts of the system, regardless of unusual drafts on any parts of the system. Pressure-equalizing standpipes or reservoirs should be located at suitably distant points from the pumping or main supply station.

5. Where dead ends are necessary as a stage in the growth of the system, they should be located and arranged with a view to connecting them ultimately so as to provide circulation.

6. Water pipes should be laid, so far as possible, above the elevation of nearby sewers and at least 10 feet laterally from them. Where this requirement cannot be met because of physical conditions, extra precautions should be taken in securing absolute and permanent tightness of water pipe joints.

7. Where a water service pipe crosses a street sewer at less than 6 feet vertically above the sewer, or is within 10 feet of it horizontally, all of that part of the water pipe lying within these distances should be constructed preferably of copper or brass pipe connected to the iron pipe with a brass fitting. In such cases it is preferable to use copper or brass pipe from the water main to the house, and the house sewers should be constructed of extra heavy cast iron with water tight joints. Where priorities necessitate the use of materials other than brass or copper, extra-heavy iron pipe should be used under these conditions.

8. Sanitary precautions should be taken in laying new water pipes. Where avoidable, pipe should not be laid in water or where it can be flooded with water or sewage in laying. Leakage tests should be made by means of hydrostatic pressure. New mains should be kept filled with a strong hypochlorite or chlorine solution (40-60 p.p.m. of chlorine) for at least 24 hours and then drained before being placed in service. Fire hydrants should not be drained into the sewers or storm drains. Valve chambers should be of watertight construction and should not be connected directly to a storm or sanitary sewer.

C. CROSS AND OPEN CONNECTIONS

1. In general, no physical cross-connection should be permitted between a public or private water distribution system containing potable water and any other system containing water of questionable safety.

2. Open connections, physically separated, may be permissible under regulation and supervision by the local or State health department.

3. House or industrial toilet or sink fixtures capable of back-siphonage into the water system should be classed as cross-connections and should be prohibited, except where supplied by an independent elevated storage tank physically separated from the water supply pipes and protected by an approved siphon-breaker inlet. Dual water systems should be avoided where possible.

PART IV

A. Discussion of Chemical Requirements for the Revised Drinking Water Standards

It is fairly obvious that a water which is turbid, or colored to a degree which is easily noticeable, or which has an unpleasant or unusual odor or taste, will be looked upon with suspicion by the consumers to whom it is served for drinking purposes. For this reason its use should not be permitted where clarification of the water is practicable, or where a more acceptable supply is available.

The presence of considerable amounts of calcium and magnesium salts makes the water unsuitable to use for washing, and it is also unpleasant for drinking to persons who have been accustomed to softer water, but persons who are accustomed to the harder waters may find the softer waters less agreeable to their taste. Although it is open to question whether it would be justifiable to require the dilution of hard water by distilled water in order to keep within the limits specified in the Standards, it would be proper to require carriers to select the local supplies which most nearly fulfill the requirements of the Standards with respect to mineral content.

Insofar as the chemical composition of the water may cause inconvenience by its irritating effect upon the intestinal canal, or by any more serious effect upon well-being, the certifying authority will be justified in requiring that due regard be paid to this matter by common carriers. Unfortunately, it is difficult to secure reliable information concerning the physiological activity of salts as found in waters. Idiosyncrasy is important. It is universally admitted that poisonous or otherwise harmful elements or salts in significant quantities, such as lead, hexavalent chromium, arsenic, fluoride or selenium, should not be allowed in water for drinking or culinary purposes. It is difficult, however, to fix limits for the less poisonous substances or salts which are normally present. The effect of sulfates, and especially of magnesium sulfate, is, however, well recognized, and it would be desirable to avoid the use of waters in which the concentration of these salts is sufficiently high to be annoying. The use of salts of barium or of hexavalent chromium for treating the water or water system should not be allowed on a drinking water supply. Molecularly dehydrated phosphates have come into use for water treatment but sufficient information upon the physiological effects of small amounts of these salts is not available. Consequently, their use in excess of 10.0 p.p.m. for treating any drinking water should be avoided. When waters are treated with chemicals in order to soften or to purify them, it is desirable that any excess use of the chemical be avoided. Limits for alkalinity resulting from excess lime or other softening procedures already have been suggested. More than a small amount of free chlorine (1.0 p.p.m.) or chloramine (2.0 p.p.m.) is objectionable in the effluent from a treatment plant because of resulting chlorinous taste in the water. In general, it is considered proper to insist that effort be made to find waters which are as satisfactory as possible from the standpoint of chemical characteristics, but with due regard to the region within which the water supply must be obtained.

Relation between pH, total alkalinity, hydroxide, carbonate and bicarbonate alkalinities in waters.—In the chemical analyses of water, it is often desirable to know the concentrations of hydroxide, carbonate and bicarbonate alkalinities present in the sample, as well as the total alkalinity to methyl orange. At present, according to Standard Methods (3), the OH^-, $CO^=_3$, and HCO^-_3 components of a total alkalinity are calculated from the values for the methyl orange (T) and phenolphthalein (P) alkalinities by means of the relations given in part II, section VI, paragraph 3.1 (p. 66). Experimentally, the phenolphthalein titration of samples containing carbon dioxide and mixed carbonates is far from satisfactory. Furthermore, the formulae for calculating the amounts of OH^-, $CO^=_3$, and HCO^-_3 alkalinity from the values of P and T ignore the laws of chemical equilibrium. The formulae assume that neither OH^- and HCO^-_3 nor $CO^=_3$ and CO_2 may exist in the same solution, assumptions which are quantitatively incorrect. Also the formulae give values for OH^- which too often do not check with those calculated from the pH of the water.

On the basis of the ionization equilibria of carbonates and water, DeMartini (4) formulated equations by means of which the concentrations of CO_2, HCO^-_3, $CO^=_3$, and OH^- present in a given sample can be calculated from the values for pH and total alkalinity. Moore (5), using the best available values for the ionization constants of carbonic acid and water, presents the DeMartini equations as follows:

$$(1)\ OH^-\ (\text{in terms of } CaCO_3) = \frac{5 \times 10^{-10}}{(H^+)}$$

$$(2)\ CO^=_3\ (\text{in terms of } CaCo_3) = \frac{5.61 \times 10^{-6}}{H^+} \times A$$

$$(3)\ HCO^-_3\ (\text{in terms of } CaCo_3) = 50{,}000 \times A$$

$$(4)\ CO_2\ (\text{as } CO_2) = 9.70 \times 10^{10} \times (H^+) \times A.$$

Where A is the factor

$$\frac{\dfrac{T}{50{,}000} + (H^+) - \dfrac{10^{-14}}{(H^+)}}{1 + \dfrac{11.22 \times 10^{-11}}{(H^+)}}:$$

in which T stands for total alkalinity and (H^+) represents the hydrogen ion concentration and is related to pH by the expression $pH = \log \frac{1}{(H^+)}$.

The total alkalinity is an equilibrium mixture of its OH^-, $CO^=_3$, and HCO^-_3 components. If the amounts of OH^-, $CO^=_3$, and HCO^-_3 in a given alkalinity are expressed in terms of percentage of the total alkalinity, any given equilibrium mixture can be represented by a point on a triangular coördinate diagram. The triangular diagram has for its three coördinates the per cent fractions of each of the three alkalinity components, OH^-, $CO^=_3$, and HCO^-_3. These vary from 0 per cent at the three sides of the triangle to 100 per cent at the opposite apex.

Using Moore's equations, the amounts of OH^-, $CO^=_3$, and HCO^-_3 in equilibrium with each other at pH values ranging from 7.0 to 11.6 for alkalinity values of 25, 50, 75, 100, 150, 200, and 300 p.p.m. were calculated, converted to the per cent fraction basis and plotted on the triangular diagram. The curves show how the relative proportions of OH^-, $CO^=_3$, and HCO^-_3 for any given alkalinity change with pH. In the diagram there are presented curves for waters with total alkalinities of 25, 50, 75, 100, 150, 200, and 300 p.p.m. (heavy solid line curves). The thin lines running from the base of the triangle to the opposite apex (100 per cent OH^-) represent samples of any given pH and show how for any given pH the relative amounts of OH^-, $CO^=_3$, and HCO^-_3 will vary with total alkalinity.

The proposed Standards set the following limits: (1) the water shall not have a pH greater than 10.6, and (2) the carbonate ($CO^=_3$) alkalinity shall not exceed 120 p.p.m. The thick broken lines represent these limits. All samples whose compositions are represented by points to the left of the 10.6 pH tie-line and above the 120 p.p.m.

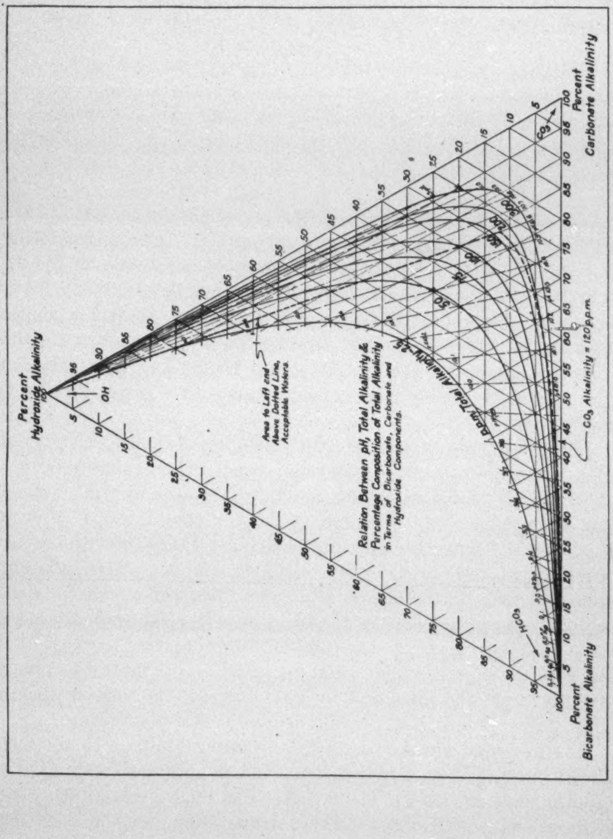

FIGURE 2.—Relation between pH, total alkalinity, and percentage composition of total alkalinity.

$CO^{=}_3$ line are acceptable. All samples of composition represented by points to the right of and below the limiting lines are to be rejected.

Because chemical equilibria are affected by change in temperature and by changes in the ionic strength of the solution, Moore's equations are strictly valid only for waters at 25° C. and low dissolved solids concentration. (Ionic strength is more or less proportional to dissolved solids concentration.) However, for practical purposes the equations will hold quite accurately for all pH values up to 10.0 in waters containing up to 500 p.p.m. dissolved solids at temperatures from 15° to 25° C.

B. DISCUSSION OF BACTERIOLOGICAL REQUIREMENTS FOR THE REVISED DRINKING WATER STANDARDS

The bacteriological examinations which have come to be recognized generally as of most value in the sanitary examination of water supplies are:

(1) The count of total colonies developing from measured portions planted in agar or gelatin plates and incubated for 48 hours at 20° C.

(2) A similar count of total colonies developing on agar plates incubated for 24 hours at 37° C.

(3) The quantitative estimation of organisms of the coliform group by applying specific tests of mlutiple portions of measured volume.

Of these three determinations, the test for organisms of the coliform group is almost universally conceded to be the most significant because it affords the most nearly specific test for the presence of fecal contamination. Only this test has been included, therefore, in the bacteriological standard recommended, as neither the 37° C. nor the 20° C. plate count would appear to add information of sufficient importance, for the purpose of these Standards, to warrant their inclusion in the required examination. The omission of plate counts from the Standards is not to be construed, however, as denying or minimizing their importance in routine examinations made in connection with the control of water purification processes.

For the purposes of the Standards the coliform group is defined as including all organisms considered in the coli-aerogenes group as set forth in Standard Methods for the Examination of Water and Sewage, eighth edition (1936), as prepared, approved, and published jointly by the American Public Health Association and the American Water Works Association, New York City.

In accordance with this definition, the Standard provides that the procedure required for demonstration of the coliform group be as prescribed in Standard Methods, eighth edition, 1936, referred to above, for the tests designated:

(*a*) The completed test, or

(*b*) The confirmed test, when a liquid confirmatory medium (brilliant green lactose bile broth, 2 per cent) is used, provided the formation of gas in any amount in this medium during 48 hours of incubation at 37° C. is considered to constitute a positive confirmed test, or

(*c*) The confirmed test where (1) crystal violet lactose broth, (2) fuchsin lactose broth, or (3) formate ricinoleate broth are used; providing the worker demonstrates the conformance of results, obtained with these three media, to the required conditions.

Moreover, it is recommended that this reference to Standard Methods shall be considered as applicable to all details of technique, including the selection and preparation of apparatus and culture media, the collection and handling of samples, and allowable intervals between collection and examination. As the standard procedure cited in this reference does not require differentiation between the various forms or types which are included under the general definition of the coliform group as given above, it has not seemed advisable, in the present state of knowledge, to require such differentiation in the application of the Standards. Two considerations tend to militate against the necessity or propriety of complicating the Standards by the incorporation of such differentiation. First, an analysis of the records of a considerable number of municipal water supplies during the past 20 years suggests that the coliform group has served effectively as an indicator of fecal pollution when the procedure for the determination of the coliform group was carried out in exact accordance with the methods specified. Second, competent research findings indicate that all constituent members of the coliform group are usually found in human fecal material. Consequently, it seems advisable to emphasize here a strict observance of the methods referred to, rather than to introduce any unnecessary procedures for the the differentiation of the coliform group.

The principles involved in the quantitative interpretation of fermentation tests according to the "most probable number" concept, in multiple portions of equal volume and in portions constituting a geometric series, were discussed fully in appendix III of the Standards promulgated in 1925 and since then this discussion has been amplified by various authors. As these principles now are understood universally and enumeration procedures concerned are used quite widely, it has not appeared necessary to repeat this discussion in the current revision. The testing of multiple portions of equal volume affords a more precise measure of the density of the coliform group within a relatively narrow range of variation than does the testing of portions in geometric series. Therefore, as the waters which will be offered for certification should represent only a narrow range of very moderate pollution, the Standards require that the examination of each sample shall consist of the separate testing of five equal portions either of 10 ml. or of 100 ml. each.[2] For laboratories which are equipped to make such tests, the examination of the larger, 100 ml., portions provides for: (1) a more definitive measure of the density of coliforms in the range of about 1 per 100 ml., as established by the Standards, and (2) information as to the approach of unfavorable conditions in the water.

The procedure for the examinations of 100 ml. portions offers no difficulty in laboratory technique, the only additional requirements being larger containers, larger quantities of media, slightly greater incubator space, and the collection of a larger sample. If economy of incubator space is desirable, multiple-strength lactose broth may be used in conformity with the provisions in Standard Methods of Water Analysis. In practice it has been found satisfactory to use standard dilution water bottles of 160-180 ml. capacity as tubes or containers for the 100 ml. portions. These bottles, containing 30-35 ml. of quadruple-strength lactose broth and equipped with the ordinary inverted vial or with a Cowles (6) tube, are sterilized in the usual manner. For convenience in checking volumes, or to eliminate the necessity for the use of volumetric pipettes, the bottles may be graduated at the 35 ml. and at the 135 ml. points. This procedure lends itself readily to the planting of samples directly into lactose broth at the site of collection of the sample.

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[2] It is advisable, however, especially in the examination of waters of unknown quality or which may be suspected to be highly polluted, to make simultaneous tests in portions of a geometric series, ranging from 100 ml. to 1.0 ml. or less.

There is, of course, no essential reason why the number of portions tested should be five rather than some larger number, except that labor and materials are limited, and five portions are considered sufficient for such precision as is ordinarily necessary.

With reference to the total number of samples which should be examined, the intervals at which they should be collected, and the location of the sampling points on the distribution system, it is recognized that such requirements are affected by (1) the nature of the source of the water, (2) the character and the consistency of the treatment provided, (3) the sanitary conditions of the distribution system, (4) the average daily volume of water delivered to the distribution system, and (5) the total population served. It is obviously desirable, from the standpoint of precision and significance of results, to examine a large number of samples collected at frequent and regular intervals, and, when normal conditions obtain, preferably at uniformly spaced points on the distribution system, but when abnormal conditions exist, at such points as will produce the maximum information concerning the cause of any abnormalities in water quality. It is obvious also that it is not practicable to lay down hard and fast requirements adapted to the qualities of each supply in question. It has appeared desirable, however, to establish for the ideal supply a requirement for the minimum number of samples to be collected and examined during specified intervals, based on the population served, and to delegate to the inspecting officer, who should have knowledge of the conditions affecting the supply in question, the authority to increase the number of samples required and to fix the times and the sites for collection of samples on the distribution system.

In accordance with these principles, the first requirement stated in the Standards, namely, that "of all the standard 100 ml. or 10 ml. portions examined per month in accordance with the specified procedure, not more than 60 per cent or 10 per cent, respectively, shall show the presence of organisms of the coliform group," may be interpreted as implying that the mean density of organisms of the coliform group shall not exceed about 1 per 100 ml. The second clause of the Standards, which specifies that not more than 20 per cent (or 5 per cent when 10 ml. portions are examined) of samples tested (or not more than one sample if the whole number tested be less than 20 for 10 ml. portions or less than 5 for 100 ml. portions) shall show the presence of organisms of the coliform group in all five 100 ml. portions, or in three or more of the five 10 ml. portions, is more complex in its implications[3] and more difficult to explain. It recognizes that, according to the laws of chance, this result would occur in a certain small proportion of the samples tested, even though the mean density of organisms of the coliform group in the whole body of water tested actually remained constant at about 1 per 100 ml. or less and, consequently, that it warrants no inference of actual fluctuations in density unless it occurs with greater frequency than would be expected according to the theory of chance occurrences. A more frequent occurrence, sufficient to indicate occasional higher pollution, is believed, however, to be an indication of potential danger, even though the average quality of the water should be satisfactory (that is, in conformity to the first provisions of the Standards). This clause of the Standards undertakes, therefore, to set a limit to the allowable frequency of positive results in an increased number of portions of any sample. It is necessary in so doing to recognize that water supplies actually do vary in their degree of pollution from day to day, and that in many instances the series of tests which will be considered may be small; hence, the limit (20 and 5 per cent) is set at a frequency which is higher than reasonably might be expected in a large series of samples from a water in which the actual density of organisms of the coliform group never greatly exceeded 1 per 100 ml. In the case of 10 ml. portions the limit for this frequency is set at 5 per cent, which is approximately five times higher than the normal expectancy. With 100 ml. portions the requirement is somewhat more stringent as the 20 per cent frequency allowed is only about 2.5 times higher than reasonably might be expected. As the possibility of an increase in pollution is ever present, the Standards provide further that when positive results are obtained in increased numbers of portions of any sample, additional and more frequent samples shall be collected and examined. The results from such additional samples will demonstrate whether the increase in positive results are due to the probabilities of chance, or to an actual increase in density of pollution.

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[3] This was ably discussed in appendix III of the 1925 Standards and this discussion has been amplified by various authors since that time.

In the bacteriological standard which has been promulgated, the committee has undertaken to set up two controlling factors: (1) two limiting values to the density of organisms of the coliform group, one limit applying to the mean density as calculated from the entire series of tests made during any one month and one to the range and frequency of occasional deviations from this mean, and (2) failure to conform with the specified procedures for making the bacteriological examinations may be used as the basis for a refusal of certification of a supply. That is, a failure to follow the specified procedures might produce results which would not provide for a satisfactory opinion of the quality of the water supply concerned.

REFERENCES

(1) Manual of Water Quality and Treatment. American Water Works Association 1940. Reprinted 1941.

(2) Public Health Bulletins 172 and 193; also Reprints 1114, 1170, 1292, 1434, and 1565 from the Public Health Reports, U. S. Public Health Service.

(3) Standard Methods for the Examination of Water and Sewage. American Public Health Association, 1936.

(4) DeMartini, F. E.: Corrosion and the Langelier calcium carbonate saturation index. J. Am. Water Works Assoc., **30**:85 (1938).

(5) Moore, Edward W.: Graphic determination of carbon dioxide and the three forms of alkalinity. J. Am. Water Works Assoc., **31**:51 (1939).

(6) Cowles, P. B.: A modified fermentation tube. J. Bact., **38**:677 (1939).

PROCEEDINGS

FEBRUARY 1944 MEETING

Hotel Statler, Boston, Mass.
Thursday, February 17, 1944.

President Horace L. Clark in the chair.

Secretary Gifford announced the election by the Executive Committee of the following new members:

Robert E. Brown, Water Department Inspector, Beverly, Mass.; Lt. Com. Kenneth M. Clark, Sanitary Engineering Office of Superintending Civil Engineer, Area I, Brookline, Mass.; Harry B. Collins, Superintendent, Water and Sewer Department, Manchester. Mass.; Joseph C. Derby, Water Chemist, Filtration Plant, Lawrence, Mass.; Charles A. Forrest, Jr., Superintendent of Water Companies, Millbury, Mass.; James E. Fuller, Research Professor Department of Bacteriology, Massachusetts State College, Amherst, Mass.; Deane E. Hawkins, General Foreman, Keene, N. H.; John W. McCarthy, Jr., Commissioner of Water, Lawrence, Mass.; Kenneth C. F. Thompson, Superintendent, Holliston Water Co., Holliston, Mass.

LELAND G. CARLTON read a letter from S. R. Rafferty, President of the Institution of Water Engineers.

WARREN J. SCOTT presented the following resolution, sponsored by the Committee on Postwar Planning:

WHEREAS during the war there has been a cessation of construction in the water supply, sewerage, and stream pollution abatement field except as required for the promotion of the war, and
WHEREAS there are numerous water supply, sewerage, and stream pollution abatement projects which should be built upon termination of the war in the interest of the public health and welfare, to improve our water supplies and better the condition of our streams, lakes and tidal waters, and
WHEREAS men and materials will be available for such construction after the war but can be gainfully employed only if proper plans for construction are made, and
WHEREAS in some of the individual New England states there has not been set

up specific delegation of responsibility for postwar planning in the water supply, sewerage, and stream pollution abatement field,

THEREFORE, BE IT RESOLVED

1. That the New England Water Works Association records itself again as strongly in favor of planning programs for postwar construction in the water supply and sanitation field.

2. That the Association urges that in each of the New England States a postwar planning committee for the water supply and sanitation field be established.

3. That it is recommended that such committees include representatives of the state departments of health, local water utilities and other interested state and local agencies.

4. That if no committee is appointed, state postwar planning in the water supply, sewerage, and stream pollution abatement field be delegated to state departments of health and state water commissions or other state agencies concerned with water supply, sewerage, and stream pollution abatement.

5. That copies of this resolution be forwarded to the chairman of each state postwar planning board if such agency exists, and to the governor of the state.

The motion was duly seconded and unanimously carried.

A paper on "Design of the Naval Advance Base Depot Water Supply at Davisville, Rhode Island," was read by George W. Coffin, Engineer, Boston, Mass.

A paper "Some Experiences in the Chlorine-Ammonia Treatment of the Amherst Water System," was read by Professor James E. Fuller, Ph.D., Research Professor, Department of Bacteriology, Massachusetts State College, Amherst, Mass. The paper was discussed by Linn H. Enslow, George C. Brehm, Warren J. Scott, and Francis H. Kingsbury.

A U. S. Signal Corps film, "War Department Report," was shown.

MARCH 1944 MEETING

Hotel Statler, Boston, Mass.
Thursday, March 16, 1944.

President Horace L. Clark in the chair.

President Clark announced the death of Henry T. Gidley, of Fairhaven, Mass.

Secretary Gifford announced the election by the Executive Committee of the following to membership:

Members: Harold D. Kilgore, Assistant Civil Engineer, MDC, Water Division, Boston, Mass.; Clarence Jerome Dougal, Manager, New Canaan and Sharon Water Co., New Canaan, Conn.; Ernest Augustus Snow, Jr., Senior Chemist, Massachusetts Department of Public Health, Amherst, Mass.; Henry F. O'Connell, Water Commissioner, Somerville, Mass.; Irving William Whittle, Assistant Civil Engineer, MDC, Water Division, Boston, Mass.

Corporate Member: Town of Norwood, Mass.

Associate: Johnson Barker Company, dealers in water works and plumbing and industrial supplies, Nashua, N. H.

THE PRESIDENT introduced Samuel Newkirk, President elect of the American Water Works Association.

A paper "Water Supply Practices at Military Posts along the New England Coast," was read by John J. Stanton, Sanitary Engineer, U. S. Engineers Office, Boston, Mass. The paper was illustrated by lantern slides. Percy C. Charnock, President Clark, and Donald C. Calderwood took part in the discussion.

George A. Sampson, Chairman N.E.W.W.A., Committee on Grounding, submitted a progress report of the Committee.

On motion of Leland G. Carlton, duly seconded, it was VOTED that the statement of policy with reference to the grounding of electric wiring systems on water service pipes be approved by this Association, as read.

Correction

James J. Matera listed as a new member on page 84 of the March, 1944 JOURNAL is associated with the Metropolitan Water Division of the Commonwealth of Massachusetts as Assistant Civil Engineer.

INTERIM REPORT OF THE AMERICAN RESEARCH COMMITTEE ON GROUNDING

Statement of Policy of the New England Water Works Association Approved March 16, 1944

The grounding of electric wiring systems on water service pipes involves matters of policy as well as engineering and technical facts.

(1) This Association will coöperate in all practices which lead to greater safety for the public. It will continue to consider all proposed measures, which are called safety measures, to see (1) whether such measures have the importance attributed to them by their proponents; (2) whether the proposed practices are effective; and (3) whether the practices are being proposed upon grounds of economy rather than fundamental merit.

(2) This Association notes, on behalf of water works executives generally, that the grounding of electric services upon water pipes is understood to be desirable in the interest of safety of the users of electric current. It observes that water departments and companies do not install such connections; derive no benefit from them; may be damaged by them; and tolerate them only because of their reputed importance in providing electric service safely.

(3) It maintains its general objections to the systematic interchange of stray electric current from electrical distribution systems to water pipes, and its unqualified opposition to the use of the water pipe system or its connections as an essential or integral current-carrying part of any electrical distribution system. It is, however, not objecting to the current interchanges which occur during comparatively brief and infrequent intervals when ground connections are fulfilling their specific protective purposes.

(4) It considers that the present indifference of the various agencies, interested in protective grounding, in the maintenance of and continued efficiency of grounding connections is unfortunate. Such connections appear to be, after their installation and original inspection, relinquished to the customer/owner as his responsibility, although, in the main, such customers/owners do not know the pur-

pose of the connections and do not know whether or not they are affording the protection for which they are installed. The electric utility interests, the insurance interests and the municipal inspection agencies share a joint responsibility for the maintenance of protective grounding installations. The water works industry has not assumed, and does not now assume, any responsibility in the matter, except it be in the protection of the structures which it maintains in order to serve its customers.

(5) Water purveyors assume no direct or indirect responsibility or obligation in connection with the installation of water pipe ground connections, or for the maintenance of the integrity or continuity of any grounding attachment or connection made to a water pipe system.

(6) Water purveyors reserve the right to use non-metallic piping or pipe jointing materials for mains, for service piping, or for house piping, without *primary* regard to the effect that this may have on electrical grounding problems. It is the water works operator's obligation to operate and maintain his system at a maximum of efficiency and effectiveness from a water works service and economic viewpoint.

Committee of the New England Water Works Association:

WARREN A. GENTNER,
A. V. HARRINGTON,
E. E. MINOR,
GEORGE A. SAMPSON, *Chairman.*

INTERIM REPORT OF THE AMERICAN RESEARCH COMMITTEE ON GROUNDING PREPARED BY THE TECHNICAL SUBCOMMITTEE*

[*Received February 25, 1944.*]

The American Research Committee on Grounding was formed several years ago by a group of interested organizations to investigate the subject of grounding electrical distribution circuits for safety purposes, as prescribed by the National Electrical Code, with particular reference to any harmful effects from grounding such circuits on water pipes. The circumstances of the Committee's origin and the scope of its field of investigations are described later in this report.

In carrying out its assignment the Committee has followed two main lines of investigation, (1) field studies of specific cases referred to it by operating water companies, and (2) laboratory tests.

In respect to the field studies, the committee has investigated all cases it has been able to learn of and to which it has had access, where impairment of water or water supply facilities has occurred under circumstances such that the water purveyors have suspected that the trouble might have been caused by electric currents resulting from such grounding. Only cases involving alternating current systems have been reported to the Committee.

The Committee is continuing its investigations but a large amount of data has already been accumulated, from which the following findings and tentative conclusions are drawn:

SUMMARY OF RESULTS

General Data

Protective Grounding. Protective grounding of alternating-current secondary distribution circuits has been a recognized practice since 1913. At the present time this practice is almost universal.

Incidental Contacts. In most premises there are incidental metallic contacts between electrical conduit or armored cable and the various building piping systems, which in effect ground the electrical system to the water pipes.

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*This report of the Technical Subcommittee has been adopted by the American Research Committee on Grounding as an Interim Report.

Current on Water Pipes. In general, where there are water pipes in premises supplied by alternating current, part of the current will flow over the service pipes. This is usually so where more than one customer is supplied from a single transformer as is generally the case in built-up areas such as are served by public water systems.

Current on Gas Pipes. In general, the flow of alternating current on gas service pipes was very low. In two cases, however, the gas pipes carried substantial current, one of these being a welded main.

Current on Drainage Pipes. In the investigations, drainage or soil pipes were too large in diameter for the use of the clip-on ammeter, but generally the distribution of the test load current was such that it would appear these pipes did not carry current. In general soil or drainage pipes of cast iron end about five feet outside the wall of the building, being continued with tile pipe.

These items of General Data are discussed in greater detail later in this report.

Classification of Field Cases Investigated

About one hundred cases have been investigated by the Committee from 1936 to date.

Impairment of Quality of Water. About a third of the cases investigated were "blue water" complaints. These cases were mostly at premises with copper tubing in areas served by untreated well water classified as aggressive. The fact that aggressive waters, particularly well waters, may cause blue water with copper or brass piping was, of course, well known in the water works field, but it was not generally appreciated that slightly aggressive or border-line waters could also give trouble. Trouble was experienced regardless of whether the pipes carried current or not. In three cases, current was taken off the pipes, but this did not eliminate the blue water condition. In one case where, subsequent to the complaint, the water had been subjected to treatment for reducing aggressiveness, the committee found the blue water trouble had disappeared.

In the nine cases where rusty water complaints were referred to the Committee, the house piping, and in most cases the service piping, were of copper or brass.

There were only six other cases involving quality of water. Four of these were complaints of taste or odor and two were of sediment in water. In none of these cases was the trouble found to be due to current on the pipes.

Corrosion of Pipes, Tanks, etc. Eleven cases related to the failure of copper tubing or high copper alloy hot water tanks. Nine of these failures occurred in two areas. In most cases there was no current on the tank or pipe that failed. The water supply in most of these cases was classified as aggressive.

Troubles on brass pipe (6 cases) were mainly leaky joints and dezincification. Investigation of leaky joints indicated that most of them were due to poor workmanship. Dezincification occurred on pipes that did not carry current as well as on pipes that did carry current.

Failure of iron pipes (5 cases) mainly involved boiler tubes. The failure was probably due to differential aeration effects or galvanic action between the tubes and the copper heat transfer unit in the boiler.

One failure of lead pipe was due to the corrosive action of free lime in the cement on the outside of the pipe. There was no current on the pipe.

Electric Shock and Sparking. In four cases of electric shock or sparking, two were due to defective wiring and two were due to absence of protective grounding.

Two cases of shock and one of gas ignition by sparking were due to radio grounds on the house piping. In these cases the current in the grounding conductor was due to a filter condenser in the radio set connected across the power circuit.

Laboratory Tests

Laboratory tests of weight loss of metallic specimens which simulated pipes and laboratory tests on polarization indicated that alternating current did not affect the corrosion of pipes. These tests were made in weak salt solutions.

Findings

1. Grounding of electric power and lighting circuits is necessary for the safety of the customers and their property.

2. In general, grounding to metallic water pipes provides the highest degree of safety. This is because the resistance to ground of such pipes is generally lower than any other grounded metal body present, and for protection by grounding the lowest resistance grounding electrode available should be used.

3. The water piping system is of necessity in parallel with the grounded conductor of the electric distribution system. The division of current between the two systems is affected by a number of factors, one of which, but not necessarily a controlling one, is the resistance of the jointing material used in the water mains.

4. In many cases the removal of alternating current from water service pipes or mains is difficult to accomplish.

5. The voltage which produces the current over the grounding conductor and water pipes under normal conditions appears to be of the order of three to four volts. In one instance with a long service entrance cable and water service pipe, approximately eight volts were found.

6. No conclusive evidence has been found to date that alternating current of the magnitude measured by the Committee has any appreciable detrimental effect on the pipes or on the water in the pipes.

7. The galvanic couples which exist in most piping systems, between dissimilar metals, or between dissimilar surface conditions on the same piece of metal, may produce currents in the water which are much greater than those produced in the water by current flowing along the pipes.

8. The troubles from blue water which the Committee has investigated have been found to be due mainly to the action of untreated aggressive well waters on copper tubing. Small variations in impurities permitted in the manufacture of copper tubing seems to affect the extent to which blue water troubles may be experienced.

9. Numerous leaky joints in yellow brass pipe systems were found due to poor workmanship in installation. This gave rise to

some dezincification at these joints. Dezincification was also observed in some yellow brass pipes at locations other than joints.

10. If the recognized practice of grounding is not followed, there may be a hazard due to electric shock, ignition of gas, and sparking. If the grounding connection is not made on the street side of the water meter, there should be a bonding jumper around the meter to insure continuity of the grounding circuit when the meter is disconnected.

11. In about ten per cent of the cases, the grounding installations were found to be defective.

12. In order to insure more effective and permanent grounding connections to water pipes, more satisfactory methods and devices than are now available should be developed.

The evidence on which the above findings are based, the methods employed in the field and laboratory investigations, and related technical information about grounding and electric current distribution, together with the historical background to this subject, are all given in later portions of this report.

EVENTS LEADING UP TO THE FORMATION OF THE AMERICAN RESEARCH COMMITTEE ON GROUNDING

In the early days of the National Electrical Code, there was no mandatory grounding requirement. As a result of a study by a Committee of the American Institute of Electrical Engineers, grounding for ordinary alternating-current distribution circuits was strongly recommended. The first National Electrical Code to contain a mandatory grounding requirement for circuits was the edition of 1913.

In 1920, the American Water Works Association sanctioned protective grounding connections to water pipes. There had been considerable opposition to electrical interconnections between water pipe systems and electrical distribution networks. The electrical interests, however, stressed the necessity for such ground connections as the only practical means of protecting life and property. On being assured that such connections would not entail any hazard, inconvenience, or difficulty as far as the water operators were concerned, the American Water Works Association, at its 1920 Convention, approved the following resolution.

"Be it resolved that the American Water Works Association approves the practice of grounding the secondaries of lighting transformers to the water pipes, providing that the grounding is done in accordance with the rules of the National Electrical Code and National Electrical Safety Code."

In 1927 the American Water Works Association adopted another resolution which read as follows:

"Be it resolved, that the American Water Works Association in convention assembled, hereby modifies its 1920 endorsement of the grounding of the secondaries of lighting transformers as follows:

"(1) The American Water Works Association approves the practice of grounding the secondaries of lighting transformers on water pipes for the purpose of safeguarding life and property, provided that appreciable electric current flows over such ground connections only during comparatively short and infrequent intervals when the ground connections are fulfilling their specific protective purposes, and provided that such ground connections impose no responsibility upon the pipe owning company.

"(2) The American Water Works Association is opposed to the use of water pipes as electrical conductors, except as noted above, and since experience with certain power distribution practices which have come into use has shown that grounding may result, and in many cases has resulted, in hazard to the pipe structures and water works employees, it hereby withdraws its former general endorsement of grounding on water pipes."

At the convention of the American Water Works Association in 1933, a paper entitled, "Promiscuous Electric Grounding on Water Service Pipes and Mains," was presented by Hill, Meyerherm, and Cowles (Journal of the A.W.W.A., Vol. 25, No. 10). This paper briefly discussed the electrical phenomena of electrolysis. It mentioned a number of situations of pipe corrosion, discoloration, and taste and odor of water, some of which apparently were cleared up by removing various electrical grounding connections, including grounds to radio sets. The authors stated that "the examples cited . . . are admittedly rather scattered and inconclusive. . . ." They also pointed out "the need for further study and investigation."

Subsequently, in 1935, the American Water Works Association adopted a resolution which read in part as follows:

"Therefore be it resolved that the American Water Works Association in Convention assembled hereby revokes and rescinds any and all previous approval or sanction of the practice of grounding electric light and power circuits on water pipes for protective or other purposes."

In view of this resolution, the American Water Works Association would not approve the grounding provisions of the 1935 Code as adopted by the Electrical Committee of the National Fire Protection Association and submitted to the American Standards Association for approval. In the discussion which followed, the idea was advanced that the American Water Works Association would withdraw its opposition to the proposed Code, provided the whole question of grounding was referred to a Committee of representatives from national organizations for detailed study in a fair, impartial, and scientific manner.

Toward the latter part of 1935, it was mutually decided that the American Water Works Association and the Edison Electric Institute, the two organizations most directly and vitally concerned with the grounding problem, would jointly invite representatives of other interested groups to meet together for the purpose of discussing the situation with the hope that the meeting might agree upon some form of permanent organization for this specific problem.

As a result, the American Research Committee on Grounding was organized on March 17, 1936, under the sponsorship of the American Water Works Association and the Edison Electric Institute. At the organization meeting there were 28 persons present representing 18 national organizations. The participating organizations are listed in Appendix No. 1. H. S. Warren was elected permanent Chairman and C. F. Meyerherm was elected Secretary and Treasurer. The following two resolutions were adopted:

1. "To investigate and report upon, as conclusively as may be
   (A) Electrical grounding connections, made to water, gas or drainage pipes, with respect to the effects of any kinds of electrical current thereby caused to flow upon,
      (1) the pipes,
      (2) the contents of the pipes, and
      (3) fire and personal hazards;
   (B) Conditions in the electrical circuits involved which produce current flow over pipes;
   (C) Measurement of stray currents; and
   (D) Efficiency of electrical grounding.

2. "That a Technical Subcommittee be formed for the actual conduct of field and laboratory work under the foregoing scope, and that the following

organizations be invited to participate with the understanding that they will be expected to contribute in money and personnel toward the conduct of the work of the Committee:

American Water Works Association
Edison Electric Institute
American Standards Association, Telephone Group
American Gas Association
American Society of Sanitary Engineering and/or National Association of Master Plumbers

and that the Bureau of Standards be requested to participate in the work of this Technical Subcommittee."

The Technical Subcommittee, after duly considering its assignment, recommended the following program:

"1. To contact various water purveyors within a radius of 100 miles of New York City to report such cases which in their opinion may be due to grounding of electrical circuits on water pipes.

"2. That a working committee be appointed to investigate these complaints in coöperation with the local electrical and water organizations.

"3. To obtain and analyze available information relating to electrical and galvanic effects.

"4. That interested organizations carry on some laboratory experiments relating to this subject."

The program thus recommended has been generally followed and the results to date are given in this report.

As indicated by Resolution 1, the chief duty of the Committee is to determine if the grounding of electrical circuits on water pipes creates adverse effects on the pipes or the water in the pipes. It is not the primary function of this Committee to pass on the adequacy or the quality of the water supply nor on the adequacy of the plumbing practices followed. Since, however, both the nature of the water and the type of plumbing has a bearing on the problem, consideration has been given to both of these items.

That damage is caused by direct current electrolysis where stray current leaves water mains for earth is well understood. This question was thoroughly considered by the American Committee on Electrolysis and others. Our Committee has not studied the question of stray direct current electrolysis. This subject is referred to at this point because statements in published articles in the technical press both in this country and abroad show that many complaints are based on electrolysis effects produced by stray direct currents. Multiple grounding of electric light circuits in stray direct current areas may permit the interchange of direct current over the grounding connections. This is recognized in the National Electrical Code, and provision is made for the removal of one or more of these grounding connections where the current is sufficient to become objectionable.

Discussion of General Data

Protective Grounding

A ground is a conducting connection, whether intentional or accidental, between an electric circuit or equipment and earth or to some conducting body which serves in place of the earth.

A grounding electrode is a conductor imbedded in the earth used for maintaining ground potential on the conductors connected to it. In the grounding of electric circuits and equipment the grounding electrode is usually the water piping system, but it may be a separate ground obtained by driving rods into the earth or by burying large pieces of metal in the earth.

In general driven or buried grounding electrodes have a higher resistance to earth than do water service pipes and water mains.

A grounding conductor is a conductor used to connect an equipment device or wiring system with a grounding electrode or electrodes. A grounding connection as used in this report refers to the connection between the grounding conductor and the grounding electrode, generally a water pipe.

An electric service is usually grounded on the premises by connecting a wire from the neutral conductor of the circuit at the service cabinet to the water pipe. Metallic enclosures are usually grounded by a metallic connection between the grounded wire and the enclosure at the service box. The grounding of electrical circuits and enclosures is usually done by the electrical contractor who installs the house wiring. In most locations the wiring must be approved by an insurance or municipal electrical inspector before electricity can be supplied and this inspector checks the grounding connections.

Grounding of Electrical Distribution Circuits. At the present time the practice of grounding alternating current secondary distribution circuits on customer's premises where the voltage is not over 150 volts to ground is almost universal not only in this country but also abroad. It is estimated that in this country there are approximately 24 million such grounding connections. When practicable, such grounding is accomplished by connections to water piping systems. It is estimated that about 21 million of these connections are to public water supply systems.

The reasons for grounding electrical circuits are well stated in the 1940 National Electrical Code as follows: "Circuits are grounded for the purpose of limiting the voltage upon the circuit which might otherwise occur through exposure to lightning or other voltages higher than that for which the circuit is designed; or to limit the maximum potential to ground due to normal voltage."

As an example, a lightning surge may cause a transformer to fail in such a way that the high primary voltage may be impressed upon the house wiring. If the circuit is not grounded, the high voltage may remain on the house wiring indefinitely and thus create both a life and a fire hazard. If the circuit is grounded, the voltage is held to a low value and the resulting current flow to ground will operate protective devices and deënergize the circuit.

Grounding of Metallic Enclosures for Electrical Conductors and Equipment. In regard to the grounding of metallic enclosures of electrical equipment such as conduit, metal boxes, and the like, it has long been the practice, with some exceptions, to ground such metallic parts. This is generally done regardless of the voltage or type of circuit involved. In this connection the National Electrical Code states:

> "Exposed conductive materials enclosing electric equipment, or forming a part of such equipment, are grounded for the purpose of preventing a potential above ground on the equipment."

Grounding not only limits potentials on metallic enclosures but also is helpful in promptly deënergizing circuits when a fault occurs. To illustrate, if a conductor within an ungrounded conduit should fail in such a way that it comes in direct contact with the conduit, the conduit will become alive and be a hazard to persons who may come in contact with it. If the conduit is grounded and a live wire comes in direct contact with it, the voltage to ground will be kept low and the current to ground will cause the fuse to operate and disconnect the circuit.

Reason for Using Water Pipe as a Grounding Electrode. The lower the resistance to ground, the better is the protection afforded. The reason why water pipes provide the best grounding electrode and why it is necessary to use them for grounding the electric circuit is well expressed in a paper presented by H. S. Warren to the New England Water Works Association (Vol. XLVIII No. 3). He states:

> "The reason why a continuous metallic public supply water piping system makes the best ground is not because such pipes have water in them but is due to the fact that such a piping system has by far the largest contact surface with the conducting material of the earth. In fact, where such a piping system exists, it is the earth, electrically speaking, for all practical purposes. The hazard to be protected against arises from the fact that voltages may accidentally be set up between different metallic objects in the house and that persons may be subjected to these voltages. Water pipes appear at numerous points through the house and are interconnected or in contact with steam pipes, gas pipes, etc., so that they offer numerous chances for people to get in contact with them. If some other grounding electrode were employed instead of the water pipes, the voltages between electric wiring, apparatus, etc., and this extensive system of pipes might be much larger and, hence, the hazard much greater. The very presence of these piping systems in a house increases the importance of using them as grounding electrodes."

Incidental Contacts. In a large number of situations the electrical system will be grounded to the piping system even though a separate grounding electrode is provided for the electrical system. For example, at many of the premises investigated there were metallic contacts between water pipes (including steam pipes connected to the water pipes) and electric conduit or the armor of armored cable. Some contacts are obtained from direct connected apparatus such as motors on oil burners and water pumps. Most of the contacts, however, are incidental such as metallic contacts between conduits, pipes, hot air ducts, etc. In general, it is impracticable to avoid such contacts, particularly where there is metal lath or other steel work in the building. These contacts, in fact, ground the electrical system on the water pipes but they are not reliable, and sparking may occur at such points of contact, particularly during lightning storms or at times of power faults. If the two systems are solidly connected, sparking will in general not occur.

Even if the two systems are kept free from contact with each other throughout the entire premises, and the electric circuit is connected to a separate grounding electrode, nevertheless some part of the current flowing in the grounding connection and electrode will flow to the water pipe through the earth. In other words, if the water pipes are not used as the grounding electrodes, and separate grounding electrodes are used, the current on the water pipes will not be completely eliminated.

In this connection it is interesting to mention an investigation made by the Committee at a hospital consisting of several buildings, where the electrical specifications had provided that no conduit should touch steam or water pipes and no wires from conduits or electrical apparatus should be grounded to water pipes, steam pipes, or other piping in buildings or tunnels. Separate grounding electrodes were provided for every building. Resistance measurements indicated that the grounded conductor was metallically connected to the piping structure in the building, that the piping systems were metallically connected through metal lath and steel work, and that the results were the same as if the conduit had been directly connected to the water piping.

It is therefore evident that incidental contacts may collect and deliver to the water service pipe currents comparable to those normally flowing over grounding connections.

Current on Water Pipes

There has been considerable misunderstanding in regard to current flow over protective grounding conductors, under both normal and abnormal conditions. Prior to the organization of this Committee, it was the common impression that no current flowed over the grounding conductor except when the protective apparatus was functioning. However, water companies often found current on their service pipes independently of protector operation. The reason for this was not immediately apparent, but it has been made clear by this

Committee's investigations. Therefore it seems worthwhile to discuss in some detail the behavior of the currents under various grounding conditions.

Figure 1 shows an arrangement of a transformer supplying only

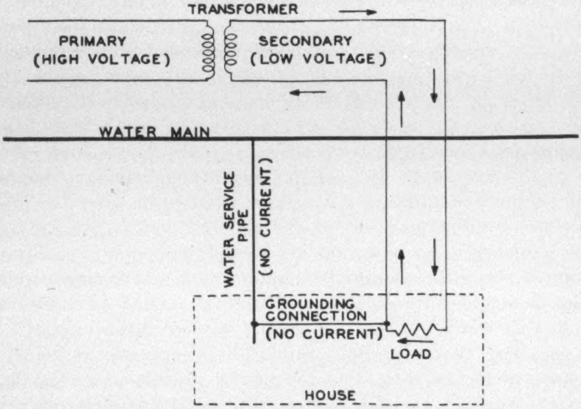
TRANSFORMER
PRIMARY (HIGH VOLTAGE)
SECONDARY (LOW VOLTAGE)
WATER MAIN
WATER SERVICE PIPE
(NO CURRENT)
GROUNDING CONNECTION
(NO CURRENT)
LOAD
HOUSE

FIG. 1.—ONE CUSTOMER ON TRANSFORMER.

one customer and provided with only one grounding connection to the water pipe. The arrows in this sketch indicate the flow of current. Under normal operating conditions and with the arrangement shown, there would be no current in the grounding conductor or water pipe.

Figure 2 shows an arrangement where two customers are supplied from one transformer but with a load at only one location. The arrows indicate the paths of the current under normal operating conditions. No attempt is made in this sketch to indicate the magnitude of current in each path, since that depends on the relative resistance and will vary with each situation. However, this sketch shows that if two or more customers are fed from one transformer and there is a water pipe ground connection at each customer, there will always be some current over the grounding connection at the water pipe under normal load conditions. The actual amount of current and its location on water piping systems will, of course, vary with each situation and also with change of load. In built-up areas where water pipes are available for grounding, there will be, as a rule, two or more customers connected to a given transformer. Since this results in two or more grounding connections on the circuit, there will, in general, be some current on grounding connections wherever there is a load on the circuit. In 51 situations investigated by the committee, the current on the water service pipe, outside the point of connection to the grounding conductor, ranged from 0 to 100 per cent and averaged about 20 per cent of the test load current. In four of these cases the current on the service pipe exceeded 50 per cent of the load current. In some instances current was found on the water pipes inside the point where the grounding connection was made, this current being due evidently to incidental contacts between metallic structures within the building.

Figure 2 shows only a two-wire circuit. However, the explanation also applies to a three-wire circuit consisting of two line conductors and one grounded conductor. In the three-wire circuit the current over the grounding conductor will be less since in this case

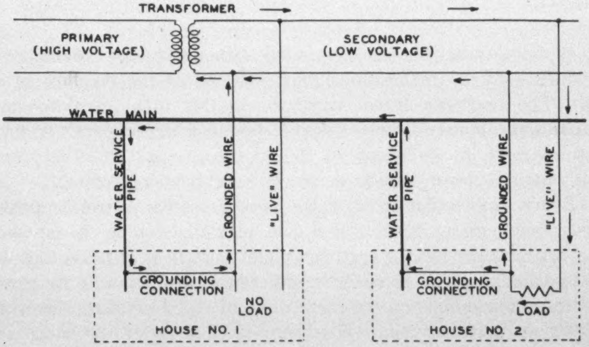
TRANSFORMER
PRIMARY (HIGH VOLTAGE)
SECONDARY (LOW VOLTAGE)
WATER MAIN
WATER SERVICE PIPE
GROUNDED WIRE
"LIVE" WIRE
WATER SERVICE PIPE
GROUNDED WIRE
"LIVE" WIRE
GROUNDING CONNECTION
NO LOAD
HOUSE NO. 1
GROUNDING CONNECTION
LOAD
HOUSE NO. 2

FIG. 2.—TWO CUSTOMERS ON TRANSFORMER.

it is a portion of the unbalance in the loads between the two sides of the circuit rather than the total load.

Under abnormal conditions, such as a failure of a transformer or where lightning potentials are impressed on the conductors, there will be relatively large currents in the grounding conductor but such currents will ordinarily last for only an instant. It is this abnormal current which causes primary fuses or overload protectors to operate and isolate the fault almost instantly. During this brief period, the grounding connections are fulfilling their protective functions and maintaining safety under abnormal conditions.

None of the cases investigated by the committee has been a three-phase system.

Galvanic Action. If two pieces of metal are placed in a chemical solution (electrolyte), but not in contact with each other, each metal will assume a definite potential the value of which depends on the kind of metal and the nature of the solution. If the two metals are dissimilar, there will be a difference between their potentials. If the two dissimilar metals are brought in contact or connected with each other, the difference in potential between them will set up a current in the solution. This current will cause corrosion of the metal of lower potential (negative electrode or anode). Such a corrosion process is called galvanic action and the combination of the two metals and electrolyte is known as a galvanic cell.

When current flows as mentioned above, a change takes place on the surface of the metal which tends to oppose the transfer of current. The opposing force developed in this manner is known as polarization. It may in some cases, depending on the metals and solutions involved, be sufficient to reduce the current to a very small value but it is never enough to block the current completely.

Every connection in a water piping system between different metals (such as a bronze valve and galvanized pipe, a galvanized boiler with copper pipe, a cast iron meter bottom with brass top) is in effect a galvanic cell. In addition, differences in the metals themselves or in the surface films on the same piece of metal or in the electrolyte may set up galvanic cells whose activity may be of the same order of magnitude as that developed by dissimilar metals. At each such point there is a current flow from one metal through the water in the pipe to the other metal. The metal from which the current leaves is corroded and some of the metal goes into solution. As pointed out in the paper by Hill, Meyerherm and Cowles, there is little polarization with flowing water. In other words, there will be a more or less constant flow of current in the water, depending on the metals involved in the galvanic cell and the electrical resistance of the water.

In the Warren paper previously mentioned, reference is made to tests with pipe couples. In these tests made with brass and iron pipe couples in tap water having a resistivity of 4,000-ohm centimeters, the resulting galvanic current (direct-current) was approximately 200 microamperes.

There are a great many galvanic couples involved in piping systems resulting from different metals, different amounts of permissible impurities in the metals, differences in film formation on the same piece of metal, particles carried into the pipes from mains, etc. It is probably the variations in the number and activity of such couples from house to house, which accounts for the wide difference in conditions observed in houses which were otherwise very much alike. The fact that such wide variations can occur in more or less similar situations may not be generally appreciated.

Current in Water Due to Current on Pipes. Pure distilled water is practically a non-conductor of electricity. Most public water supplies contain enough salts and other material to make them conducting to some extent. However, compared with any metal the most conductive water is still an extremely poor conductor. The amount of current which will enter the water due to the presence of current on the pipe will be extremely small compared to the current on the pipe. This is illustrated by a specific case given in the Warren paper mentioned above. He states:

> "A simple computation will show how much current will get into the water in a pipe due to the presence of current on the pipe. Assume a ¾-in. standard welded steel pipe and water of 4,000-ohm centimeter resistivity, a value which is within the range of commercial water supplies. The resistivity of iron and steel has quite a range of values as between different samples, but 11 microhm-centimeters represents a fair value for standard transformer steel. One ampere of direct current on the pipe would mean a voltage drop of 156 microvolts per

> foot of pipe. With water of the assumed resistivity, the resistance of a water column of 0.533-sq in. cross-section and 1 ft long is 35,000 ohms. The same voltage drop in the water as in the pipe would, therefore, correspond to a current of 4.4×10^{-9} ampere or less than one-half of 1/1,000,000 of one per cent of the current in the pipe. In the case of alternating current, the proportion of current in the water would be even less."

It is interesting to compare the current in the water due to one ampere of current along the pipe with the current set up in the water by a galvanic couple or cell as mentioned above. By comparing the two figures, it will be noted that the galvanic couple introduced 50,000 times as much current in the water as would one ampere of direct current along a ¾-in. iron pipe. In other words, the current in the water produced by the current on the pipe is extremely small compared to the current put in the water by the many galvanic couples which exist in every water system.

FIELD WORK

Obtaining Cases to Investigate. In the paper by Hill, Meyerherm and Cowles mentioned before, a request was made "that any or all information or experience with problems of this or of a similar nature (trouble due to grounding of electrical circuits) be reported to the association for study and correlation." At the organization and subsequent meetings of this Committee, request was made that complaint cases involving grounding of electrical circuits be referred to the Technical Subcommittee. Letters were written to 17 water purveyors within a 100-mile limit of New York inviting them to report cases of such trouble to the Subcommittee. Each report of the Committee, released to the technical press and widely published, carried an appeal to report cases of trouble. Nevertheless, reports have been infrequent so that at times the Subcommittee has had no cases to investigate for periods of several months. As of July 15, 1943, the Subcommittee had covered 12 listed situations. Of these, 78 were complaint cases, the others being situations which the Subcommittee elected to investigate. This means that the Committee has received an average of only 13 complaints a year to investigate, although it is not to be inferred that all water complaint cases have been brought to its attention. In a number of cases this was not desirable because of customer relations.

Method of Making Field Investigations. Upon receipt of a complaint a group was organized to investigate the case. This group consisted of two or more members of the Subcommittee and one or more persons from the water purveyors and the electric company involved. In general, the following information was obtained.

1. A detailed statement of the complaint from the consumer.
2. Details concerning the source of water supply, treatment, etc.
3. Typical analyses of water supplied.
4. Details of piping system, including street mains, service and house pipes.
5. Type of equipment on the premises, such as hot water tanks and heaters, furnaces, fixtures, etc.
6. Details of electric service, including street circuit, transformer location, house service and house wiring, including grounding.
7. Measurements of alternating currents on pipes and other metallic structures.
8. Measurements of direct current on pipes and structures.

In addition, samples of water were obtained at the premises for analysis.

In a few cases, electrical conditions were altered so that the current was entirely removed from the pipes. Subsequent investigations were made to study the effect of such changes. This is discussed later in more detail.

It was understood at the outset that many complexities would be encountered in these investigations and as the work proceeded it was found that many questions arose that had not been anticipated. Such things as variations in types and compositions of materials, in character of water and in rates of flow of water, in types of water heating equipment and temperature control, the variety of troubles complained of and apparent inconsistencies in the effects, have often made it extremely difficult to determine just what causes were responsible.

Analysis of Situations Covered. The situations investigated may roughly be grouped as follows:

Impairment of quality of water	
Blue (or green) water including staining of fixtures	34
Rusty or dirty water	9
Taste or odor	4
Sediment in water	2

Corrosion of pipes or equipment	
Corrosion of copper tubing or high copper alloy water tanks	11
Corrosion of brass pipes or fittings	6
Corrosion of iron pipes	5
Corrosion of lead pipe	1
Electric shock and sparking	7
Miscellaneous	9
Adjacent situations for comparison—no trouble found	14

DISCUSSION OF SITUATIONS INVESTIGATED

Impairment of Quality of Water

Blue Water (34 Cases). This type of complaint covered approximately one-third of all the cases investigated. With one exception the water service pipes at all locations were of copper tubing. The house piping in 24 cases was copper tubing and in 5 cases was brass pipe.

The water supply in 25 cases was from wells. In 22 cases there was no treatment except chlorination. In 3 cases the blue water trouble disappeared when lime treatment was applied to the water supply. The water supply involved in at least 23 cases was considered to be too aggressive; that is, some corrosion of copper tubing or brass pipe was to be expected.

In most cases some current was found on the water pipes. On the average about 20 per cent of the test load current was returned over the water pipe. However, in 5 of these complaints of blue water there was no current on the service or house piping. In three cases the current on the piping was eliminated but the removal of the current from the pipes did not alter the complaint condition.

Rusty Water (9 Cases). In one case with water pipes of copper, the hot water was rusty after a month of use of a new oil-fired domestic hot water heater. This was apparently due to the iron water tank being improperly galvanized. When the tank was replaced by the manufacturer with a new tank and the former copper connections were changed to galvanized iron, the trouble disappeared. There was some alternating and some direct current on the piping to the hot water tank.

Another of these cases is a good example of the difficulty experienced in making the field investigations. In a large house the piping, including a hot water recirculation system, was brass, the hot water tank was copper, the long 1½-in. service pipe to the street was wrought iron and the pipe from the curb to the main was lead. There was a small amount of alternating current on the service pipe and on a branch pipe to which the grounding conductor was attached. At the time of the Committee's initial inspection, the rusty water appeared at three different places, but not elsewhere in the house. The most discolored water came from a hot water tap at the most remote point in the house. Several changes in the conditions were tried out and at different times the discoloration has disappeared and reappeared. The explanation of this situation has not yet been found.

In 5 of the other 7 cases both the services and the house piping were copper or brass and in one of these five cases the service pipe carried no current. In the 2 remaining cases the house piping was brass or copper but the composition of the service pipes is not known. In one of these two cases there was no current on the service pipe.

Taste and Odor (4 Cases). In one case the trouble had disappeared before the Committee could make an investigation. In another case a cooling coil was involved which, when by-passed, substantially eliminated the trouble.

The third case involved a dead-end main combined with small usage. There was no current on the grounding conductor or pipes.

In the fourth case the trouble had practically disappeared at the time of inspection. It was attributed to low water in the reservoir.

Sediment in Water (2 Cases). In one case the sediment was iron rust. The pipes in the house were largely lead and brass, with some iron. The service pipe was lead lined iron pipe. Sediment was obtained even when water was flushed for considerable periods through a hose attached directly to the service pipe. The grounding connection was made to a steam pipe and carried part of the load of two houses which were served by one 2-wire service. At the request of the Subcommittee the ground connection was removed for several months. Subsequently, a time switch and a low voltage transformer were installed to put current on and off the pipe intermittently. These changes in applied current did not correlate with changes in the quantity of sediment found in the water. Samples of water taken from various houses along the same street showed similar sediment but in no case was the quantity as large as it was at the house under inspection.

In the second case the sediment was greenish blue particles. In order to measure the amount of sediment and at the same time eliminate the customer's complaint, a fine mesh strainer was inserted in the water service pipe ahead of the water meter. The amount of sediment was reasonably large initially but it steadily decreased over a period of several months (August-September 1939). For six months, including the winter period, there was practically no sediment, and then during the period from about August 1 to October 31, 1940, an extremely large amount of sediment was collected. After October, 1940, the sediment condition again disappeared. The water supply was treated with lime before and during the early stages of this investigation. Subsequently about October, 1939, sodium hexametaphosphate treatment was applied in addition to the lime. Then in May, 1940, the lime treatment was omitted but the phosphate treatment continued. The interesting features in connection with this case are that by far the largest amount of sediment occurred while the phosphate treatment was being used by itself and that, with the lime treatment as well as the phosphate treatment, the worst sediment occurred during August and September in two different years. During the entire time that this investigation was being conducted, no change was made in the electric wiring and therefore there should have been no significant change in the current being carried by the pipes.

Corrosion of Pipes or Equipment

Corrosion of Copper Tubing and High Copper Alloy Hot Water Tanks (11 Cases). Five cases involved failure of copper tubing and six failures of tanks. Six failures were in one water area and three were in another area. In seven of the locations the Committee found that the water had a blue tint, especially when soap was added. The water supply on all these cases is classified as aggressive. In four cases there was no current on the pipe or tank that failed and in one case there was a small amount of current.

One case where copper tubing within a building failed is of considerable interest. Both the service and house piping were copper tubing. The service tubing had a firm adhering coating of a protective character on the inside while the house tubing which failed had loosely adhering tubercles on the inside, affording little or no protection. There was current on the service pipe but none on the house piping. Subsequent investigation showed that the phosphorous content, while within specification limits, was twice as great in the house tubing as in the service tubing.

Corrosion of Brass Pipe and Fittings (6 Cases). A piece of pipe removed by a plumber showed signs of severe dezincification. No current was found on the pipe which replaced the dezincified pipe. It should be noted that some dezincification was found on yellow brass pipe in several different locations. Dezincification was also found on pipes that did not carry any current. Four cases involved leaks and formation of corrosion products at threaded joints. Upon investigation it was found that the joints leaked due to improper threading of the pipe. Such leaky joints occurred on pipes which did not carry current as well as on pipes which carried current.

In one case a leak was due to corrosion of a brass washer used in a compression fitting for making up copper tubing. This washer was found to be made of so-called free turning brass which readily corrodes.

Corrosion of Iron Pipes (5 Cases). Four of these cases involved failure of boiler tubes or associated piping. Electrical measurements did not reveal any alternating currents on the pipes connected to the boilers. Some direct current was found which might have been due to a galvanic couple created by the iron of the boiler and the copper heat transfer unit.

The remaining case was merely an inspection of a situation where the galvanized service was so badly choked up with rust as to permit the flow of only three gallons of water per minute.

Corrosion of Lead Pipe (1 Case). The lead service pipe was corroded on the outside. It failed when a meter was being reconnected. There was no current on the pipe or the grounding conductor. The corrosion was apparently due to the action of alkali in the cement in which the pipe and ground clamp were imbedded.

Electric Shock and Sparkling (7 Cases)

It seems worth while to discuss each case in some detail.

Case No. 18. A meter man observed sparks when he replaced the water meter at a residence. Investigation showed this was due to a radio ground. The radio ground was opened and 9,000-ohm voltmeter inserted between it and the water-pipe. The potential measured was 35 volts a-c and when an ammeter was substituted for the voltmeter a current of 5.4 milliamperes was observed. The radio set had a line noise filter in which there is a condenser connected between the line conductor and ground. The voltage here involved is in no way hazardous since the high impedance of the condenser limits the current to a few milliamperes. The use of such noise filters is very common in radio sets. It should also be pointed out that a shock can only be obtained when the house piping (with meter out) is completely isolated from ground.

Case No. 28. A gas company employee was repairing a leak in a small restaurant. In order to make repairs, two regulators and two gas meters were removed. The pipe was plugged but the gas was not shut off at the valve. When one of the regulators was being replaced, the gas flow from the service pipe ignited and a serious fire occurred. This ignition was attributed to an electric spark. Investigation showed that the electric wiring was proper and grounded to the water pipe. Further investigation showed that the house gas piping was substantially free of grounds when the meter was disconnected. A radio set which was grounded to this gas pipe had a filter with a 0.01-mf condenser connected across the power leads in the set. This condenser could pass a current of approximately 5 milliamperes to ground. It seems reasonably certain that a spark resulting from the breaking of this current while replacing equipment caused the ignition of the gas.

Case No. 31. Plumbers disconnected a steam pipe from the heating furnace, and while it was so disconnected received a shock between the steam pipe and furnace. Investigation showed that the radio set was grounded to living room radiator which was connected to this pipe. This brought about a condition similar to that discussed in detail in Case 18.

Case No. 30. Due to digging operations in a street in connection with building a sewer, a copper water service pipe had been disconnected from the street main. Subsequent to a lightning storm, the foreman attempted to reconnect the service and received a shock. A water company man equipped with rubber gloves connected the service but in doing so obtained a spark. Investigation showed that a lighting fixture had sparked during the storm and was put out of service. The fixture apparently became energized and in turn energized the armored cable which was in contact with the water pipe. In this case the grounding conductors had previously been cut off or broken off. It is of interest to note that, with the grounding conductor properly connected, the low resistance thus provided would have resulted in the operation of the fuse when the armored cable became energized. Thus the shocks and sparking which were observed about one hour after the storm would not have occurred.

Case No. 45. This was a case of "flash and electric shock" during the removal of a water meter. Investigation showed that someone had added several single wire extensions from the "hot" wire using the water pipe as the other side of the circuit. In addition, there were several open twisted splices without tape or other protection. These were flagrant violations of the National Electrical Code. It is of interest to note that between the time of complaint and the investigation, a fire occurred in the basement as a result of which part of the basement wiring had been renewed. However, enough of the old wiring was left to indicate clearly what the original condition must have been.

Case No. 48. This was reported as a blue sediment complaint. In connection with the investigation it was decided that a short section of pipe be removed from the service about 50 ft from the house for inspection. The plumber who removed the pipe reported "spark" and "shock" in taking out the piece of pipe. When the pipe was again disconnected in the presence of Subcommittee members noticeable sparks could be observed especially if a hack saw blade was used to short-circuit the space between the pipe ends. With a load of 10 amperes in the house and with hands thoroughly wet, several of the investigators could just get a slight sensation of shock when the pipe was firmly grasped, one hand on each side of the open ends. The following measurements were obtained.

Current on service pipe with 10-amp load in house (gap in pipe closed)	2.5 amp
Voltage across gap in pipe with 10-amp load in house	3 volts
Voltage across gap in pipe during starting of electric washing machine	10 volts

Note—These voltage values were relatively high since there was only a two-wire electric service and it was about 250 ft long.

Case No. 70. The complaint was that an employee of the water company received a severe electric shock when changing the water meter. Investigation showed that the neutral conductor was open at the house end of the service from the pole so that all the current returned via the water pipe. In addition the grounding connection had been made to a cold water pipe about 30 ft from the meter and no bonding jumper had been placed around the meter as required by the Code and recognized practice. It is of interest to note that this shock would not have occurred if the installation of the grounding conductor had been properly made.

To summarize, the shock and spark situation may be divided into two classes; those due to radio sets which on open circuit can be felt but are not dangerous to life, and those which were due to the fact that the electrical installation was not grounded or was improperly grounded. There were no cases of appreciable shock (other than from the radio sets) where the electrical wiring was in accordance with recognized standards.

Miscellaneous (9 Cases)

None of these cases involved complaints. They merely cover certain investigations and inspections made by the Subcommittee.

One water purveyor had two separate well supplies in the same general area. One supply was treated with lime. The other supply was not treated. The following is a comparison of the analysis of water taken from the treated and untreated supply:

	No Treatment	With Treatment
CO_2—free	22.7 p.p.m.	0.4 p.p.m.
pH	5.4	7.1
Alkalinity—eq $CaCo_3$		
Carbonates	0	0
Bicarbonates	10 p.p.m.	25.5 p.p.m.
Hydroxides	0	0
Iron—Total	0.13 p.p.m.	0.58 p.p.m.
Copper	0.64 p.p.m.	0.08 p.p.m.

Note—In both cases the service and house piping were copper tubing.

In two situations measurements were made on services supplied by transite mains. These measurements showed that individual services may have a fairly high resistance to ground. However, the resistance at any given point was low due to the fact that many such services were tied together through the grounded neutral power conductor.

Two cases involved a study of current flow on mains in an excavation.

One case involved inspection of grounding arrangements at a hospital as previously mentioned.

One case covered an inspection of 40-year old house pipe which was being removed.

In one case electrical grounding was not involved. The premises were located close to a power substation. Apparently at the time of a power fault there was a large current which passed from the water pipe to the gas pipe. At the point of contact between gas and water pipes, they had welded together.

Defective Grounding Installations

In eleven of the situations investigated, the grounding installations were defective. Three of these were due to the ground clamp being poorly attached to the pipe, as a result of which there was little or no current over the grounding conductor. In four cases the grounding conductor had been removed, broken or cut. In two cases no ground had been placed. In one case the connection was made to a steam pipe. In two cases the grounded conductor was open so that all the load current returned over the service pipe.

The relatively large number of defective grounding installations is disturbing and indicates the need of some means whereby better installation and maintenance of protective grounds may be attained.

Ground Clamps

The Subcommittee found that many types of ground clamps were being used and that the clamps were not always well suited for the particular situation involved. In some cases, ground clamps, although they seemed to be tight, nevertheless were not making metallic contact with the pipe. There was also some corrosion at clamps. In one case, this corrosion was sufficiently severe to have caused a pipe failure. With many varied piping conditions encountered both as to piping material used and location, a clamp type of connection will not in many cases provide a connection of permanence and reliability. This question has been given considerable study by the Subcommittee which has come to the conclusion that some form of lug as an integral part of a pipe fitting would be very helpful towards making a permanent and effective grounding connection for the power service.

Removal of Current from Water Pipes

In most situations encountered where there is current on the water pipes, the disconnection of the grounding conductor from the water pipe will not eliminate the current, since, as explained before, in most premises there are incidental contacts between conduits or cable armor and water pipes. In order to eliminate the current it is necessary to remove the bond between the service cabinet and the neutral conductor, and so arrange the grounding connection that the equipment remains grounded. Unless the neutral conductor is well grounded elsewhere it is also necessary to run a separate grounding conductor from the neutral to an independent ground, such as a driven pipe. Another method of eliminating the current is to leave the grounding connections undisturbed and to provide a separate transformer to serve only the premises on which the current is to be eliminated. In most existing installations it is difficult to apply either of these methods.

However, the wiring in four situations was modified to eliminate the current. In none of these cases did the elimination of the current modify the complaint condition. This observation combined with the fact that there were complaints in twelve situations where there was no current on the pipes, accounts for the fact that only in four situations was the current eliminated by modifying the wiring.

Laboratory Investigation

The committee sponsored certain laboratory tests in regard to polarization and effect of alternating currents on pipes.

Simulated Pipe Tests. These tests were conducted in the latter part of 1937 and early part of 1938.

The purpose of the simulated pipe tests was to determine under laboratory control and on an accelerated basis whether or not superimposed alternating current on a water pipe containing galvanic couples between dissimilar metals would stimulate or retard the action of these galvanic couples. For use in these tests, electrode assemblies as shown in the attached Figure 3 were used. Each electrode assembly consisted of two copper and two zinc pieces placed alternately on a hard rubber rod.

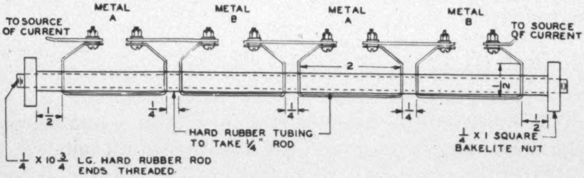
METAL A
METAL B
METAL A
METAL B
TO SOURCE OF CURRENT
TO SOURCE OF CURRENT
2
$\frac{1}{2}$
$\frac{1}{4}$
$\frac{1}{4}$
$\frac{1}{4}$
$\frac{1}{2}$
$\frac{1}{2}$
HARD RUBBER TUBING TO TAKE ¼" ROD
$\frac{1}{4}$ X 1 SQUARE BAKELITE NUT
$\frac{1}{4}$ X 10$\frac{3}{4}$ LG. HARD RUBBER ROD ENDS THREADED.

FIG. 3.—SIMULATED PIPE ELECTRODE.

In each test, six electrode assemblies were placed in pans approximately 4 inches wide, 12 inches long and 1½ inches deep and were partially immersed in 400 cc of a weak salt solution. Electrode assembly No. 1 had no connections between the metal pieces. Electrode assemblies Nos. 2 and 3 had connections between the adjacent metal pieces to permit exchange of current from galvanic action.

The remaining three electrode assemblies had the metal parts connected in series and had various values of alternating current passing along the electrode assembly.

The results obtained from these tests are given in the following table:

Loss of Weight of Zinc Samples
(Milligrams)

Arrangement of Electrodes	Test A Total	Test A Per Day	Test B Total	Test B Per Day	Test C Total	Test C Per Day	Average Daily Loss Tests A, B & C
No Connection	746	26.6	342	16.3	327	15.6	20.2
Connection	2760	98.6	838	39.9	813	38.7	63.0
Connection	2654	94.8	834	39.7	851	40.5	62.0
Connection and 30 mils a-c	2267	81.0	742	35.3	636	30.3	52.0
Connection and 300 mils a-c	2839	101.4	936	44.6	874	41.6	66.4
Connection and 3.0 amps	2615	93.4	1077	51.3	740	35.2	63.3
Strength of NaCl	1/50 N		1/500 N		1/500 N		
Resistance between metal pieces	One Ohm		0		0		
Days tested	28		21		21		

It is evident that a large part of the corrosion found in these simulated pipe tests was due to galvanic action. The results do not indicate that the presence of the alternating current on the electrodes had any material effect on the magnitude of corrosion or loss of metal.

Effect of Alternating Current on Polarization. A series of tests was made to determine to what extent alternating current on pipes caused depolarization of galvanic couples which are present in all piping systems. These tests were made between April 1938 and May 1940.

At each galvanic couple or cell in a water pipe, there is a current flow through the water from one electrode metal to the other electrode metal. This current ordinarily corrodes one of the electrodes and also causes metal to go in solution. As a result of the current flow, a

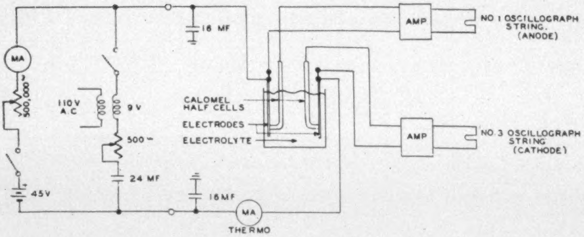

FIG. 4.—SCHEMATIC CIRCUIT FOR POLARIZATION TEST.

change takes place at the surface of the electrode which tends to oppose the flow of current. The opposing force developed in this manner is known as polarization. It is equivalent to a counter E.M.F. It may in cases be sufficient to reduce the current to a very small proportion of the initial value but it is never enough to block the current completely. Other factors such as oxidizing agents tend to destroy the conditions which reduce the current. This action is known as depolarization. In general, any effect which increases polarization will reduce corrosion and any effect which depolarizes or reduces the polarization will increase the corrosion.

In the case of water pipes it is generally recognized that flowing water is an active depolarizer and therefore prevents the slowing down of the rate of corrosion at galvanic couples.

In the following tests, cells consisting of two electrodes immersed in a solution of .1 normal sodium chloride were used. The general plan followed for these tests is shown in the attached Figure 4. For tests using direct current only, the switch in the alternating-current supply circuit was left open, and in tests with alternating current only, the switch in the direct-current supply was left open. In the tests with alternating current superposed on direct current, the direct-current switch was closed first and after proper interval of time the alternating current switch was closed. With both switches closed, practically no alternating current passed through the direct-current circuit because of the high resistance of the control rheostat. The direct current could not go through the alternating-current branch due

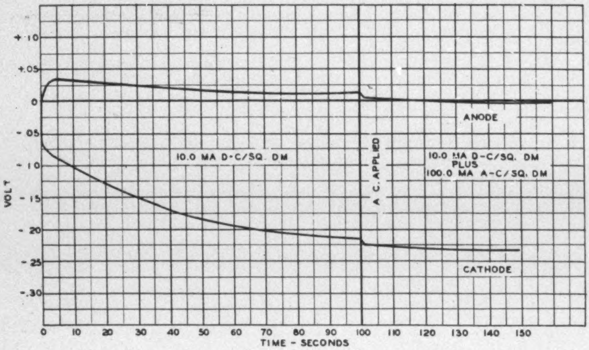

Fig. 5.—Effect of Alternating Current on D-C Polarizatlon of Zinc.

to the use of a condenser in this circuit. In all tests with both alternating current and direct current, the direct current was applied first and the alternating current later, usually after an interval of about 100 seconds. The polarization potentials were measured by means of calomel half cells and a recording oscillograph.

Fig. 5 shows polarization effect with zinc electrodes. It will be noted that the effect of superposed alternating current is small (applied at the 100-second point) even though the alternating current was 10 times the direct current.

Fig. 6 shows similar curves for copper. Here again the effect is small and is practically negligible at the anode (corroding electrode).

While it is admitted that these laboratory tests do not closely simulate field conditions, they nevertheless do establish the fact that superposed alternating currents do not materially alter polarization on water pipes.

Pipe Tests. Several years ago one of the water purveyors conducted tests of various kinds of pipes, some carrying no current, some alternating current and some direct current. The water from the various pipes was tested for metal contents at stated intervals. However, the results obtained were not conclusive. In view of this,

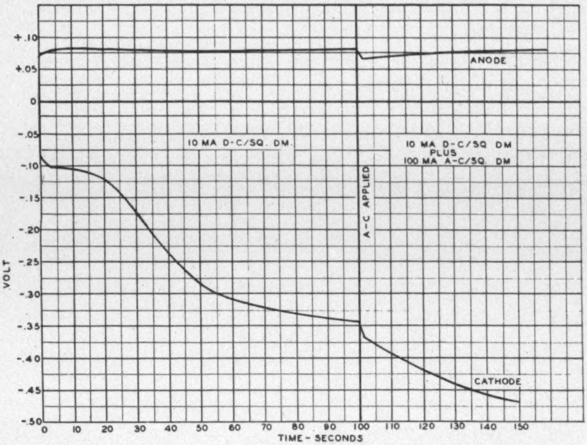

FIG. 6.—EFFECT OF ALTERNATING CURRENT ON D-C POLARIZATION OF COPPER.

the Committee felt that the tests should be repeated, avoiding as far as practicable those conditions which, based on the previous tests, might lead to error in the results.

The Committee has been unable to conduct such tests. However laboratory tests on sections of pipe carrying water are now being conducted by the American Water Works Association and New York University, in an attempt to determine whether current on the pipes affects the metal concentration in the water delivered from the pipes. So far these tests have not progressed to a point where indicative conclusions can be drawn.

Investigation in England

In 1938, the British Electrical and Allied Industries Research Association, at the request of the Institute of Civil Engineers, prepared a program for research on "Earthing to Water Mains." Early in 1940 this association published a Technical Report entitled "Critical Resume on the Corrosion of Metal Pipes with Particular Reference to Earthing to Water Mains" by Messrs. L. H. Daniel, G. Mole and S. Whitehead.

This report is an extensive review of the literature on corrosion, and includes many references to publications in this country. Mention is made of the fact that this review was preliminary to making the investigations noted above. No additional information has been obtained from England and it is presumed that no appreciable amount of this work will be carried out until after the war.

August, 1943

Technical Sub-Committee
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H. E. KENT
J. S. McCLENAHAN
C. F. MEYERHERM
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APPENDIX NO. 1

List of Organizations Represented at the Meeting of March 17, 1936

American Gas Association
American Institute of Electrical Engineers
American Society of Sanitary Engineers
American Standards Association (Telephone Group)
American Transit Association
American Water Works Association,
Association of American Railroads
Copper and Brass Research Association
Edison Electric Institute
International Association of Electrical Inspectors
National Association of Master Plumbers
National Board of Fire Underwriters
National Bureau of Standards
National Electrical Contractors Association
National Electrical Manufacturers Association
National Fire Protection Association
New England Water Works Association
Radio Manufacturers Association

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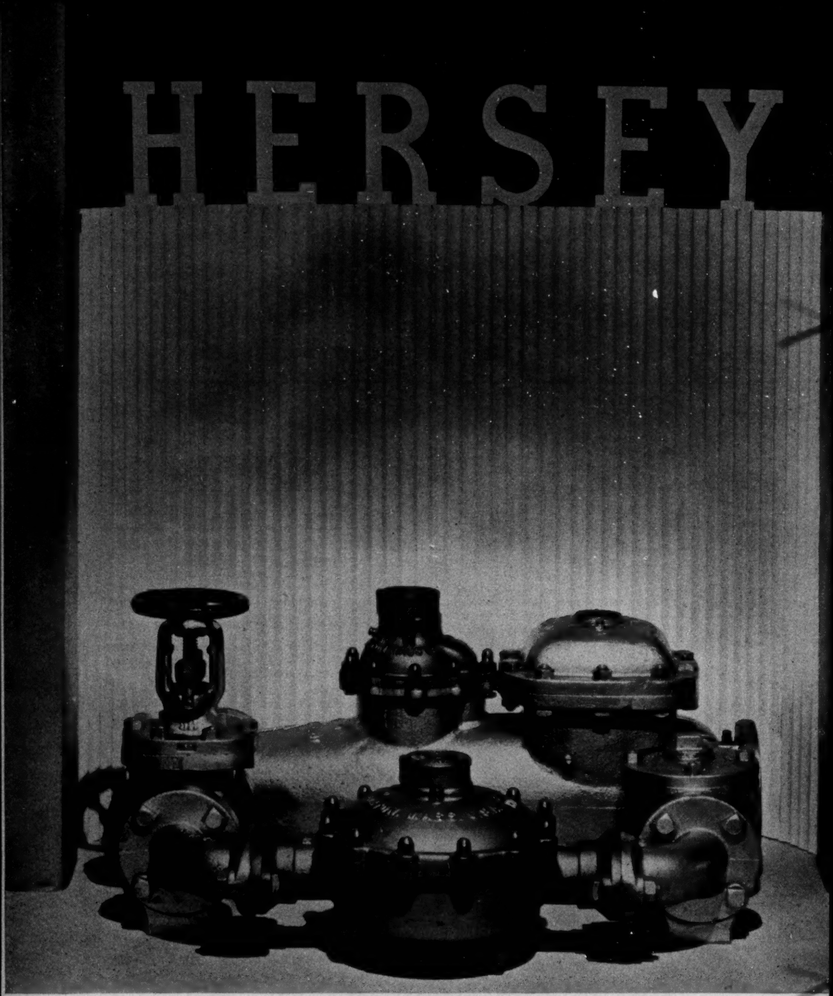

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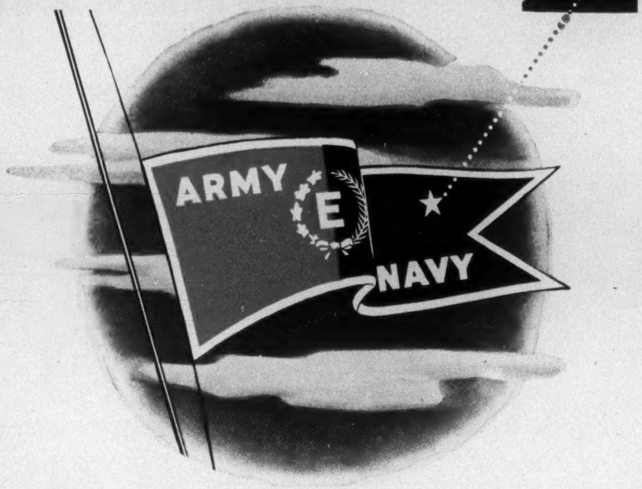


Loyally and eagerly, Badger Meter men and women continue to serve for victory, backing the attack by outstanding production of materials needed for war — keeping faith with their co-workers who are now in the Armed Forces.

With understandable pride, Badger Meter folks point to the first star in their coveted Army-Navy "E" pennant that has flown over the Badger Meter plant since June 18, 1943 — tribute to their continued outstanding achievement in war production.

The durability built into Badger Meters and the easy interchange of parts enable water works men to maintain Badger accuracy at commendably low cost, despite wartime restrictions on critical metals. In your postwar planning, put Badger Meters first.

BADGER METER MANUFACTURING COMPANY
MILWAUKEE • WISCONSIN
Branch Offices: New York City, Tampa, Fla., Seattle, Wash. Savannah, Ga., Kansas City, Mo., Marshalltown, Iowa, Waco, Texas, Los Angeles, Calif., Chicago, Ill., Philadelphia, Pa.

BADGER Water METERS
ACCURACY · LOW COST MAINTENANCE · DURABILITY · SENSITIVENESS

CUE FOR YOU FROM THE BIGGEST JOBS

WORTHINGTON-GAMON
3810808
WATCHDOG
ARMY
E
NAVY

Why **WORTHINGTON-GAMON** *Water Meters Get the Call on the Largest Contracts*

Here are the reasons why Worthington-Gamon Water Meters have been specified on the largest contracts ever awarded in the United States.

1. Long-life performance, result of the longest experience of any water meter manufacturer.
2. Low-cost maintenance, result of famous Worthington manufacturing controls, established by this leader among firms supplying many types of equipment to municipalities.
3. Ability to measure minims of water, result of improved Worthington-Gamon design.

In addition to these essentials, Worthington-Gamon offers the most extensive service facilities of any meter company . . . 24 district offices in 24 leading cities plus Worthington Research Laboratories including a staff of highly skilled water meter technicians.

When you specify Worthington-Gamon Water Meters, you too will benefit by the reasons that get first call for Worthington-Gamon Meters on the largest contracts.

The Meter Specified in the Largest Contracts Ever Awarded in the U. S.

Subsidiary of

WORTHINGTON PUMP AND MACHINERY CORPORATION

Power Plant Equipment • Turbines & Turbo-Generator Sets • Condensers, Heaters, Ejectors • Water Purification Equipment • Diesel & Gas Engines • Pumps, Stationary and Portable Compressors • Air-Conditioning & Refrigerating Equipment • Power Transmission Equipment • Construction Machinery, Equipment for Mines • Locomotive Feedwater Heaters • Welding Positioning Equipment • Liquid Meters

WG-4-3

WORTHINGTON-GAMON METER COMPANY

282-296 South Street, Newark, New Jersey

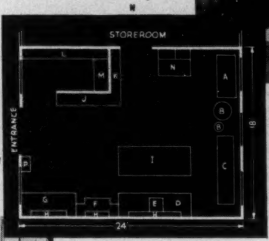
"Watchdog" models . . . made in standard capacities from 20 GPM up; frost proof or split case in household sizes. All parts interchangeable with your present meters of our manufacture. Write for Bulletin.

Your Meter Shop *deserves careful planning*

METER TESTING AND
REPAIR SHOP
ILLINOIS WATER
SERVICE CO.
CHAMPAIGN, URBANA,
ILL.

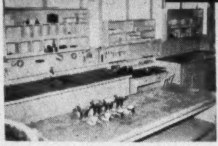
• *J. A. Mitchell,*
Foreman

Above: North Elevation of Meter Shop, Cleaning Bench in lower center.



A —Single unit test bench for large meters.
B —Ten cu.ft. and one cu.ft. tanks used with both A and C.
C —Ten unit test bench for small meters.
D —Two space meter repair bench L. 8', W. 30", H. 37".
E —Sink countersunk in above.
F —Small parts bench. For registers, gear trains, etc. L. 5', W. 23", H. 31".
G —Finishing bench for repaired meters L. 6'3", W. 30", H. 37".
H —Wall bins and tool boards containing parts and tools for use at respective benches.
I —Service bench used in conjunction with D. L. 8', W. 36", H 37". Underneath metal top this bench is divided into four equal shelves thus providing storage for 120 incoming meters and meters in various state of repair.
J —Storage for finished ⅝" meters. Capacity 160 meters.
K —Storage for finished ¾", 1", 1½" and 2" disc meters. Capacity: ¾"-12, 1"-10, 1½"-4, 2"-3.
L —Floor to ceiling, parts storage shelves in alcove, made by J. & K.
M —Double deck shelf for portable test meter and field testing equipment. Also in alcove.
N —Desk and filing cabinet for individual meter records.
P —Electric grinder and polishing wheel.

Below: Work Bench Section. Center section for Gear Trains and Registers. Note orderly tool arrangement, also special tools, casing, stocker, control block locator, gear train block, etc.



"A STUDY of the location of various fixtures will show that a minimum of handling is necessary, as the action of both repairing and testing takes place in a comparatively small centralized area."

THIS brief comment by Mr. J. A. Mitchell, Foreman of the Meter Department, indicates the important features of a modern meter repair shop in the mind of an experienced operator—features designed to "facilitate repair and testing in view of the trend toward more accurate registration at the minimum flows and . . . to enlarge our production capacity for a program . . . proven to be essential."

86

BLUE
PRINT
NOW!

AWWA NEWWA
FSWA WSWMA
Committee on Water and Sewage Works Development

● ***Mr. Mitchell may be justly proud of his repair shop, and we are proud of the part that Trident representatives had in working with him.***

NEPTUNE METER COMPANY • 50 West 50th Street • New York 20, N.Y.
Branch Offices in CHICAGO, SAN FRANCISCO, LOS ANGELES, PORTLAND, ORE.,
DENVER, DALLAS, KANSAS CITY, LOUISVILLE, ATLANTA, BOSTON.
Neptune Meters, Ltd., Long Branch, Ont., Canada

Attention Mr. Water Works Superintendent ! !

CEMENT LINED SERVICE PIPE:—

Resists Corrosion

Has proven practical for nearly three-quarters of a century

Immediate delivery can be made to waterworks on both wrought iron and steel, black or galvanized.

"SPECIFY EUREKA PIPE"

EUREKA PIPE COMPANY, Inc.

Manufacturers of CENTRIFUGAL CEMENT LINED PIPE and LEAD AND TIN LINED FITTINGS

591-593 WASHINGTON ST. TEL. 3-9550 LYNN, MASS.

Health and Protection First

Water delivered through dirty pipes may be a MENACE.

Incrusted water pipes mean inefficiency and loss of Fire Protection.

We Guarantee the Results of Our Method of Cleaning.

WRITE US.

National Water Main Cleaning Co.

30 Church Street New York City

New England Representative:

J. B. CONNERS

115 Peterboro Street, Boston 15, Mass.

Cement Lined Service Pipe

Cement lined pipe has eliminated corrosion and metal contamination for 60 years

Write for Literature

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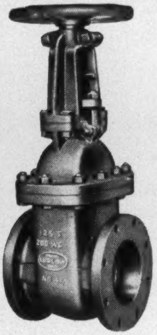
LUDLOW EQUIPMENT

Proved by the Past - - Fit for the Future

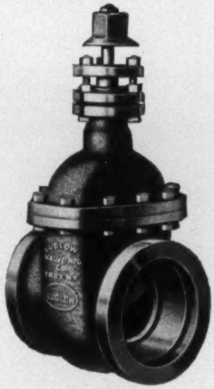
Write for full information



←Iron body, bronze mounted — tested at 350 lbs. hydrostatic pressure. List 44—sizes 2″ to 12″—200 lbs. working pressure. List 66 —sizes 14″ to 48″—150 lbs. working pressure.

Outside Screw and Yoke Type

Iron body, bronze mounted — → complying with latest A.W.W.A. Specifications. Tested at 300 lbs. hydrostatic pressure. Sizes 2″ to 48″.



A.W.W.A. Double Disc Gate Valve

←Iron body, bronze mounted—low pressure valves. List 3 Valves made in sizes 2″ to 48″ and can be furnished with Hub, Flanged, Universal, Spigot, and Screwed Ends.

Valve shown with Hub Ends and without gearing. Also available with gearing or outside screw and yoke—and flanged ends.

←Hydraulic Cylinder, iron body, bronze mounted—manufactured in all sizes for any desired test or working pressures. Can be operated by four-way cocks or remotely controlled by solenoid valves.

Flanged End Standard Gate Valve with Cast Iron Bronze Lined Hydraulic Cylinder.

The LUDLOW SINCE 1866
VALVE MFG·CO·INC·
TROY·N·Y·

HYDRO-TITE

AND DRY BRAIDED FIBREX

A DEPENDABLE SELF-CAULKING JOINT COMPOUND FOR CAST IRON BELL AND SPIGOT WATER MAINS

HYDRO-TITE is a self-caulking sulphur base jointing compound used to joint bell and spigot cast iron water mains and soil pipe. It comes in powder form which insures uniformity and quick melting.

When poured into a joint, HYDRO-TITE immediately solidifies upon contact with the metal and bonds to both the surfaces of the bell and the spigot for the entire depth of the joint. It requires no caulking and after pouring a joint, water pressure may be immediately applied.

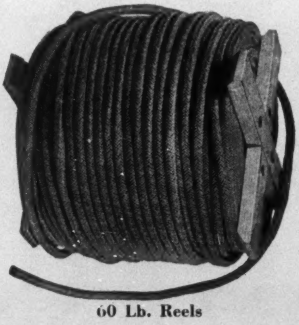
HYDRO-TITE is easy to use, no skill being required to make joints that are tight from the start. Joints made with HYDRO-TITE will stand any pressure the pipe will stand.

DRY BRAIDED FIBREX →

USED LIKE BRAIDED JUTE
WILL NOT BREED BACTERIA

A SANITARY Packing used in jointing bell and spigot pipe for water, sewer mains and soil pipe.

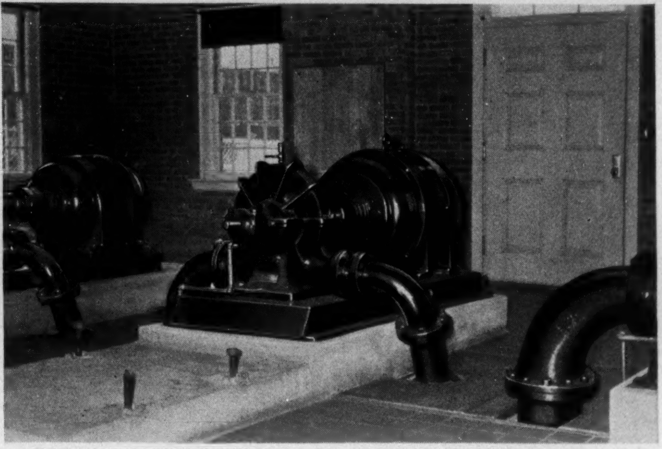
FIBREX was designed for use with Hydro-Tite and other self-caulking compounds, but is entirely suitable also for joints made with lead, and for Sani-Tite and other asphalt sewer joint compounds. Thousands of pounds of Fibrex are already in service on water lines throughout the country.



60 Lb. Reels

HYDRAULIC DEVELOPMENT CORPORATION

Main Sales Office: 50 CHURCH STREET, NEW YORK, N. Y.
Works: WEST MEDFORD STATION, BOSTON, MASS.



Methuen booster station able to move daily quota of 4½ million gallons with three Fairbanks-Morse centrifugals.

EXACTLY THE RIGHT PUMP

There are no adjustments on a pump. It is designed and built to do one job. At this job it will work efficiently, and at any other it will not.

Fairbanks-Morse builds with the best of materials, workmanship and engineering research. The result is a line of uniformly good pumps. In addition, Fairbanks-Morse takes the utmost care to see that exactly the right pump is chosen for each job.

A Fairbanks-Morse engineer is on call to help you solve your pumping problems. Write Fairbanks, Morse & Co., 178 Atlantic Avenue, Boston 10, Massachusetts.

FAIRBANKS MORSE Pumps

DIESEL ENGINES
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ELECTRICAL MACHINERY
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RAILROAD EQUIPMENT
WATER SYSTEMS
WASHERS-IRONERS
FARM EQUIPMENT
STOKERS
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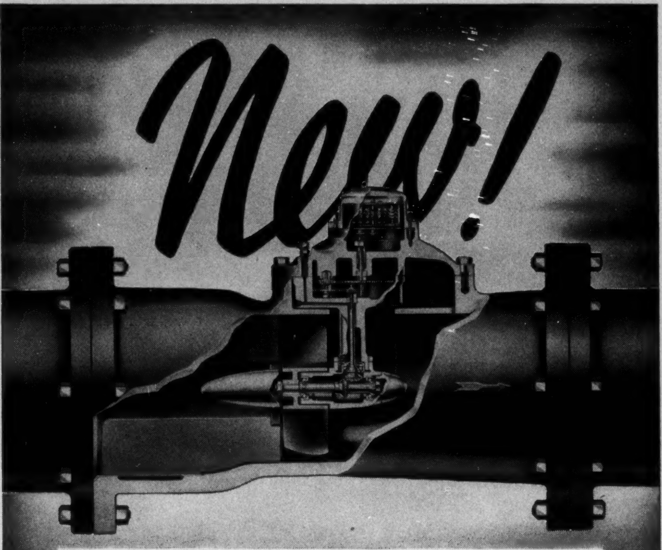

. . . IMPROVED TOTALIZING PROPELLER TYPE FLOW METER WITH STREAMLINE VENTURI DESIGN

BUILDERS
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A low price accurate meter incorporating BUILDERS traditional excellence of design and workmanship. For complete information, address Builders-Providence, Inc., (Division of Builders Iron Foundry), 9 Codding Street, Providence 1, R. I.

"BLUE PRINT NOW"

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.... and, of course, for Water Gates we want Kennedy

WATER gate specifications naturally demand flexible, positive, uncomplicated operating mechanism . . . gates that close tight, open easily, remain dependable through long service. When you specify Kennedy A. W. W. A. Water Gates, you do so because you know you're getting the utmost in efficient, trouble-proof service . . . assured by a reputation established through 65 years of valve-designing experience.

Built to give extra value. Stems whose strength exceeds standard A. W. W. A. specifications. Seat and disc rings that give extra wear, cannot work loose. Bodies, bonnets and flanges extra heavily proportioned. Stuffing boxes extra long and deep, easily adjusted. Wedging mechanism positive in action. Bolts and nuts that defy rust.

KENNEDY
K V
150 W
12
1939

Non-rising stem, bell-end type Kennedy Water Gate Valve

Kennedy A. W. W. A. Water Gates are supplied in a full range of types for all water-works requirements in size, pressure, control. For descriptions, specifications, complete information, see latest Kennedy Catalog. 240 pages.

The Kennedy Valve Co. Elmira, N.Y.

KENNEDY
A.W.W.A. WATER GATE VALVES

EDDY

Valves and Hydrants

Distinctive Features of the EDDY Valves

ONLY three parts are moved by the Stem—the ball and the two gates. Each gate is hung from one of the trunnions on the ball. A convex surface at the base of each trunnion fits a concave surface on the back of the gate. This allows the gates to adjust themselves properly to their seats. . . . The gates, being free to revolve on the trunnions, do not always seat in the same position. Gates are center bearing and adjustable. They are forced to their seats with equal pressure at all points. There are two hooks on the ball on sizes 4-inch and larger, which loosely engage with the gates.

Distinctive Features of Our New Swivel Top Hydrants

THIS new hydrant has all the advantages of the popular EDDY fire hydrant, plus several additional features. . . . Nozzles are in a short flanged section of the standpipe, which may be unbolted and turned to different positions. . . . Should the standpipe be broken, only the casting below the swivel head need be replaced. . . . To raise the hydrant to conform to a new grading, simply insert a flanged extension piece below the swivelhead. No digging. To add a steamer nozzle at any time, it is only necessary to replace the swivel head with one having a steamer nozzle.

Besides valves and hydrants to meet the most exacting demands of waterworks service, the complete EDDY Line includes: valves for sewage disposal works; valves for steam, gas and oil; check valves, foot valves, plug valves, shear gates, indicator posts, etc. EDDY valves are made in three classes: Iron Body Bronze Mounted, All Bronze, and All Iron Valves.

●

Eddy Valve Co.

WATERFORD NEW YORK

WHEN LAYING WATER MAINS TODAY . . .

Remember that joints caulked with lead are soft and flexible . . . take up normal pipe movement without leakage . . . stay tighter longer.

Remember, too, that there is no current shortage of lead . . . no ruling which prohibits the use of lead for caulking purposes.

We furnish lead either in ingot form for cast joints or as lead wool for cold caulking. Both carry the Lead Industries Association Seal of Approval—a guarantee of their purity.

National-Boston Lead Company
900 ALBANY STREET BOSTON, MASS.

INGOT LEAD — LEAD WOOL — LEAD PIPE
SOLDER — WHITE LEAD — RED LEAD

Of Course there are OTHER Good Jointing Compounds

. . . but none of them offers all the advantages you get in

Tegul-MINERALEAD

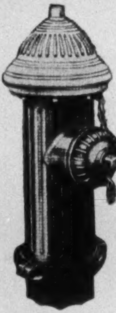
Here they are. Read them over:

1—Much lower initial leakage.
2—No separation of ingredients under transit-to-job jolting.
3—Immunity to rain and flood when stored unprotected on the job.
4—Much easier, handling, shipping and storing.
5—No need of skilled labor or deep bell holes.
6—Sound, sturdy joints with much higher resistance to mechanical and thermal shock . . . and
7—*Tegul*-MINERALEAD weighs only 1/5 as much as lead, goes three times as far and is not a strategic war metal.

Stocked in principal cities over the U. S. and in Hawaii. For further money-saving, information, write

THE ATLAS MINERAL PRODUCTS CO. of PA
Mertztown - Pennsylvania

THE A. P. SMITH MFG. CO.,
East Orange, New Jersey



Manufacturers of high-grade specialties in connection with water and gas department work, consisting of—Machines for inserting valves under pressure, and for making large right angle connections to mains under pressure, and for inserting house service connections under pressure.

Also makers of—Pipe Cutting Machines, each size being adjustable for use on three different sizes of pipe.

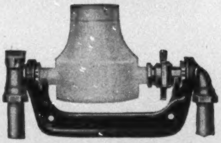
High-grade water works supplies, such as Hydrants, Valves, Meters, Corporation Cocks, etc.

We also make a new type of hydrant which has a breakable joint at the ground line which when struck with an impediment will break at a specified point and only a coupling has to be used to repair the hydrant, which will be back in service in twenty (20) minutes.

"HYDRANT WITH BREAKABLE COUPLING"

SMITH
WATER WORKS SPECIALTIES & SUPPLIES
THE A.P. SMITH MFG. CO. *East Orange, N.J.*

FORD YOKES



With the trend more strongly than ever toward greater accuracy and more frequent testing, the easy and trouble-free accessibility of a water meter set in a Ford Yoke makes this proven and perfected setting device most worth while.
Catalog sent for the asking.

FORD METER BOX CO.,
WABASH, IND.

DONALDSON IRON CO.

MANUFACTURERS
. . . OF . . .

CAST
IRON
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CAST IRON GAS & WATER PIPE

. . . AND . . .

Special Castings for Water and Gas
Also Flange Pipe and Fittings

EMMAUS, LEHIGH COUNTY, PA.

TELL US NOW

We'll Be Ready With ENOUGH *and* ON TIME!

NOW is the time for a seasonal check-up of your water works requirements. Although a large part of our facilities are being used to produce specialized items for the Army, Navy, and Air Corps, we are manufacturing a full line of Water Works Products, subject of course, to WPB approval.

We suggest that you be conservative in your estimates, but get your orders in as quickly as possible. We will be ready with enough and on time.

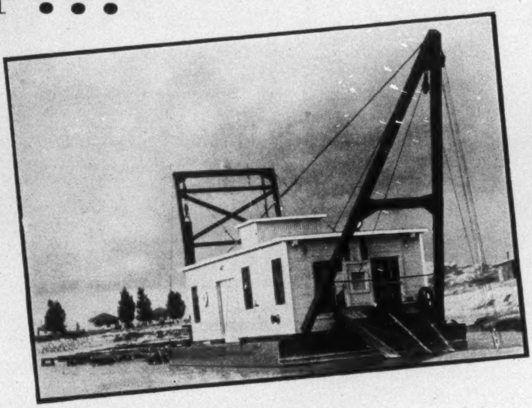
WATER
WORKS
PRODUCTS

SINCE 1869

HAYS

INVEST IN BONDS
TODAY TO PROVIDE
FOR EXTENSIONS
TOMORROW

BOTTOMS
UP . . .



IF you could see the bottom of your water supply reservoir, you would very likely be astonished at the depth of sediment and debris which has accumulated over a period of years. In many localities water storage reservoirs are gradually filling up with deposits, but this need not mean eventual abandonment of the reservoir and the high cost of building a new one to replace it. The most economical remedy for this condition is a Morris Hydraulic Dredge, which has been used for this work by municipalities and power companies all over the country—in some cases at a cost of less than 10 cents per cu. yd. of excavated material. Complete information will be sent on request.

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ESTABLISHED 1864

NEWTON,
MASSACHUSETTS

CENTRIFUGAL PUMPS

Replacing Old Pumps with New Pays Big Dividends

Many a New England Water Works is operating a pump which, even though not very old, is actually "eating its head off" in power bills.

Consider a typical case:

Rate of pumping—3 MGD **Current cost—2¢ kw/hr.**
Pumping head—231 ft. **5000 hrs. per year operation**
Assumed motor efficiency—88%

	Your Old Pump	*A New 1944 De Laval*
Pump Efficiency	72%	83%
B. H. P.	170	147
Electric H. P.	193	167

Power saved—19.4 kw. at 2¢ rate—38.8 cents/hour
Annual saving—5000 hrs. x .388 equals $1,940.00

A new 1944 DE LAVAL HEAVY DUTY WATER WORKS PUMP, with 150 hp. driving motor and reduced voltage starter, can be supplied for the sum of $2,448.00.

PERCENTAGE RETURN ON NEW EQUIPMENT = 79 1/3%

TIME REQUIRED TO REPAY FIRST COST — 15 MOS.

ANNUAL SAVING, after liquidation of investment — $1,940.00

In many instances the cost can be reduced if your present motor is satisfactory. In such cases the return is much greater.

May we work out the details of your own particular installation? No obligation, of course.

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of NEW ENGLAND
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New England Representatives for
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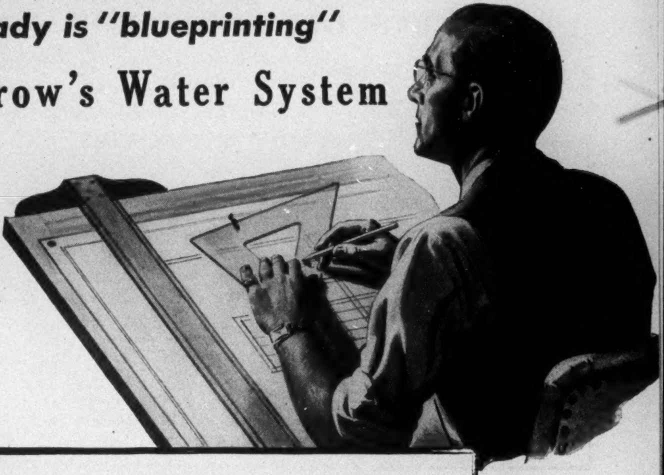
The Engineer with Vision

already is "blueprinting"

tomorrow's Water System



He is anticipating future peace-time water requirements, and planning Safety-Plus standards for pure water.

For such an engineer Wallace & Tiernan offer valuable technical information (1) on methods of application of Break-Point Chlorination for greater protection, and taste and odor elimination; (2) on the practice of installing Duplicate Units to assist in handling peak loads and to meet any emergency; (3) on the use of Automatic Control of application to maintain a safe chlorine residual throughout the distribution system.

See your W&T Representative or write to the W&T Engineering Department.

"The Only Safe Water is a Sterilized Water"

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MANUFACTURERS OF CHLORINE AND AMMONIA CONTROL APPARATUS
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Flanged Pipe *Flexible Joint Pipe*
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Special Castings *Short Body B. & S. Specials*
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Large Stock Enables Us to Make Prompt Shipments

For an Extremely Smooth Pipe Interior

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SPUN BITUMASTIC LINING

REG. U.S. PAT. OFF.

This Will Assure You of

NO LOSS IN CAPACITY
NO TUBERCULATION OR INCRUSTATION
NO EFFECT ON WATER QUALITY

Recent Repeat Flow Test Shows High Williams Hazen Coefficient Unchanged After EIGHT YEARS

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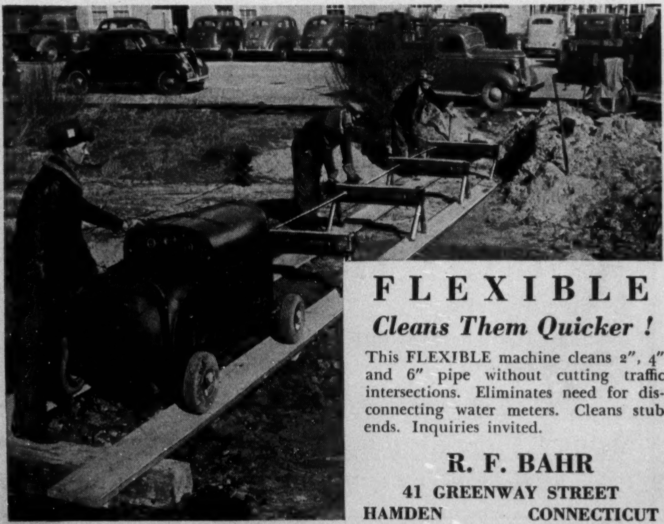

FLEXIBLE

Cleans Them Quicker !

This FLEXIBLE machine cleans 2", 4" and 6" pipe without cutting traffic intersections. Eliminates need for disconnecting water meters. Cleans stub ends. Inquiries invited.

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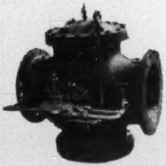
41 GREENWAY STREET
HAMDEN CONNECTICUT

1879—ROSS—1879

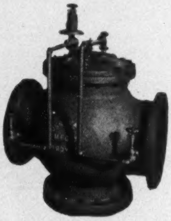
AUTOMATIC VALVES



Controls elevation of water in tanks, basins and reservoirs

ALTITUDE VALVE

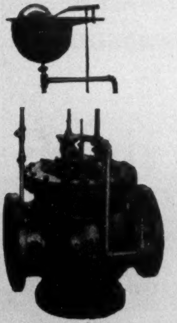
1. Single Acting
2. Double Acting



Maintains desired discharge pressure regardless of change in rate of flow

REDUCING VALVE

Regulates pressures in gravity and pump systems; between reservoirs and zones of different pressures, etc.



Maintains levels in tank, reservoir or basin

1. As direct acting

2. Pilot operated and with float traveling between two stops, for upper and lower limit of water elevation.

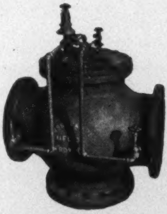
FLOAT VALVE

A self contained unit, with three or more automatic controls

COMBINATION VALVE

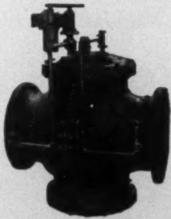
Combination automatic control both directions through the valve.

Maintains safe operating pressures for conduits, distribution and pump discharge



SURGE-RELIEF VALVE

Electric remote control—solenoid or motor can be furnished



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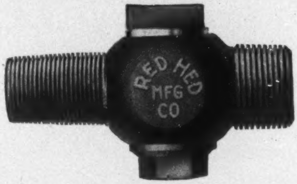

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Fig. 226
Iron Pipe or Hall Thread

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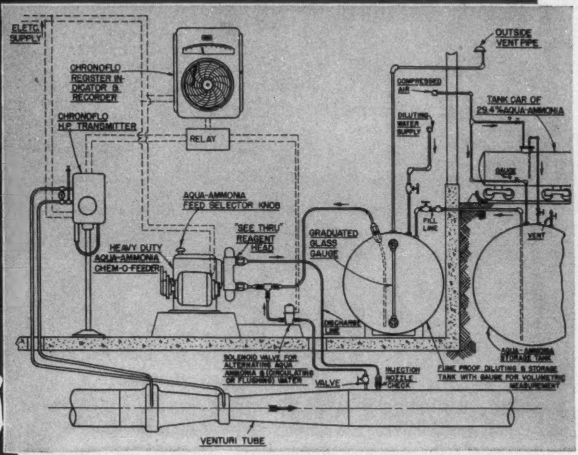
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VENTURI TUBE
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AQUA-AMMONIA STORAGE TANK

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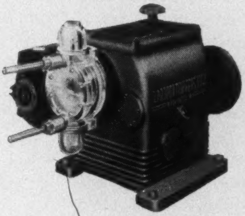

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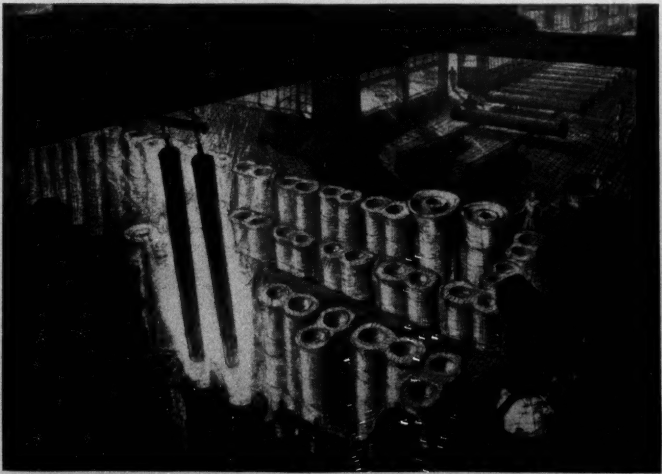

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